DOCUMENT RESUME

ED 299 160 SE 049 696

AUTHOR	Weber, Michael; Tinney, Richard
TITLE	A Nation of Oceans.
INSTITUTION	Center for Environmental Education, Washington, D.C.
SPONS AGENCY	National Oceanic and Atmospheric Administration (DOC), Rockville, Md.
REPORT NO	ISBN-0-961-5294-1-5
PUB DATE	86
GRANT	NA82AAA04132
NOTE	99p.; Drawings may not reproduce well.
AVAILABLE FROM	Center for Environmental Education, 1725 DeSales Street, NW, Washington, DC 20036 ($8.95 plus $2.00 postage and handling).
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	College Science; *Conservation (Environment); Conservation Education; *Ecology; *Environmental Education; Higher Education; Marine Biology; *Marine Education; Natural Resources; *Oceanography; Science Education; Scientific and Technical Information; Secondary Education; *Secondary School Science; World Problems
IDENTIFIERS	*National Marine Sanctuary Program

ABSTRACT

This book is for people that want to know more about the oceans, its inhabitants, and the ocean processes. The main text of the book describes individual marine ecosystems including offshore open water, benthic, nearshore tropical, nearshore temperate, and nearshore arctic ecosystems. Discussed are some of the basic ecological principles found operating in these and other ecosystems. Examples of specific research efforts are described to illustrate how scientists go about uncovering information about life in the oceans. The examples are drawn from parts of the National Marine Sanctuary Program to emphasize the need for conservation of selected marine areas in the United States. (CW)

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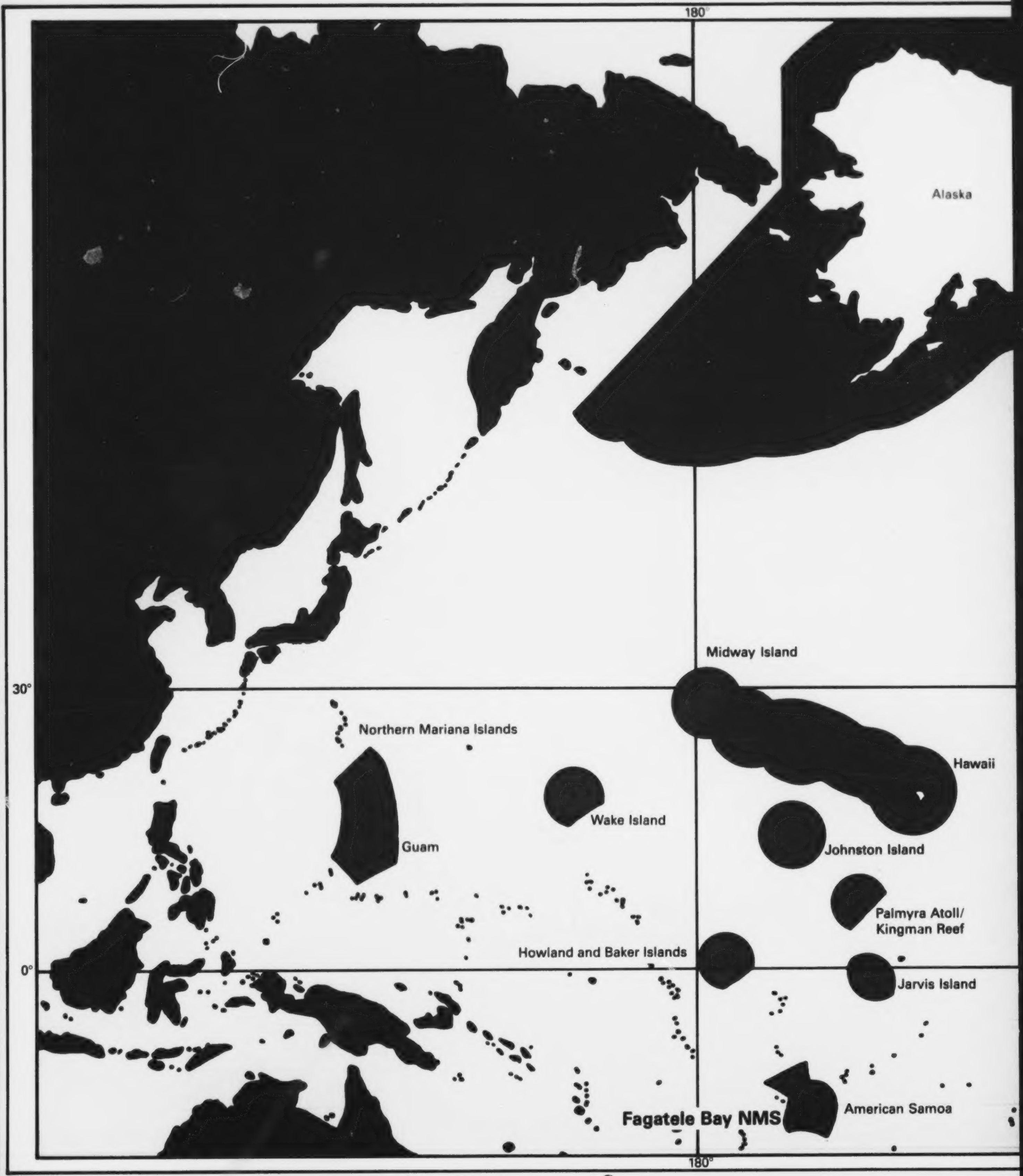
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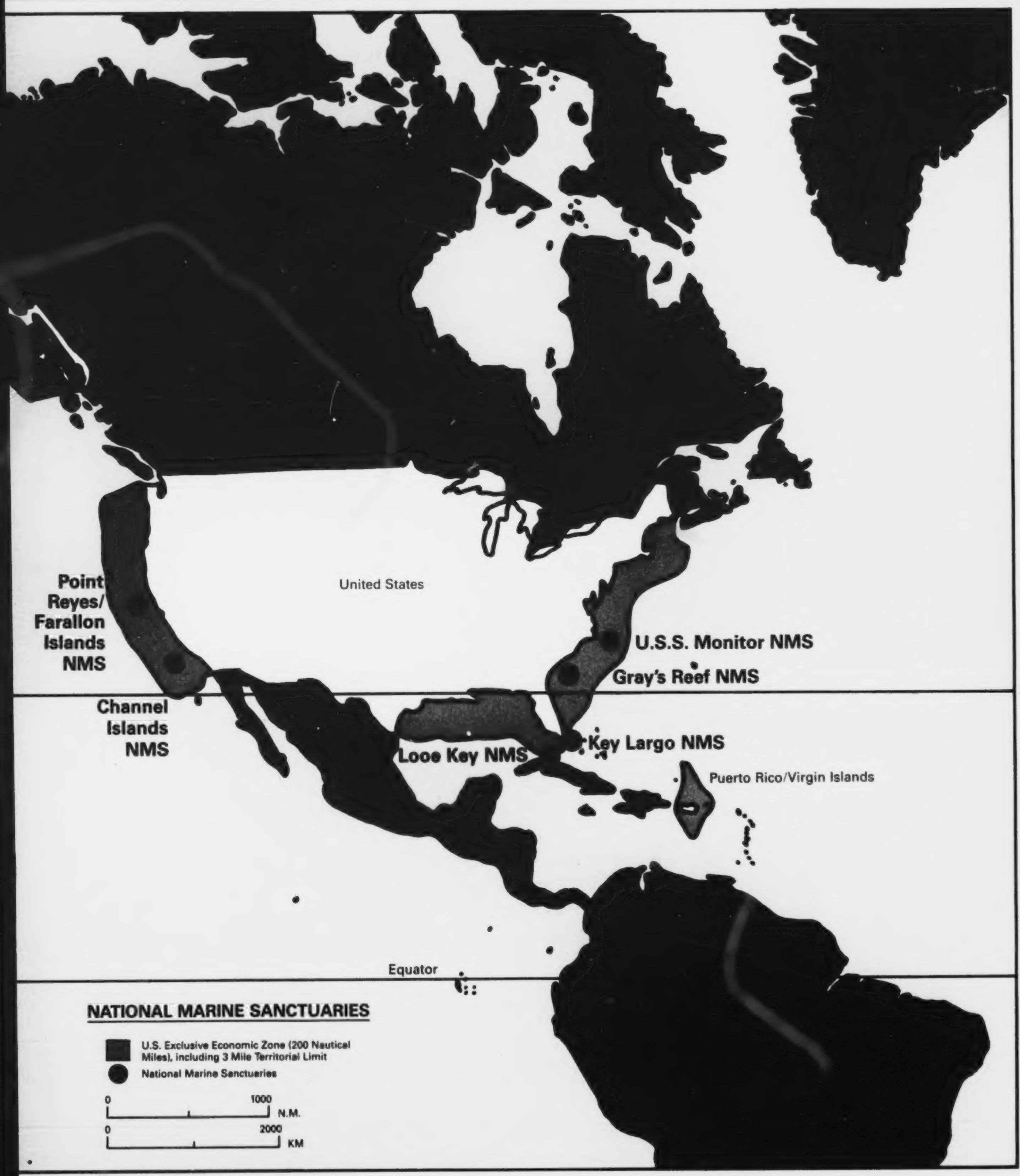
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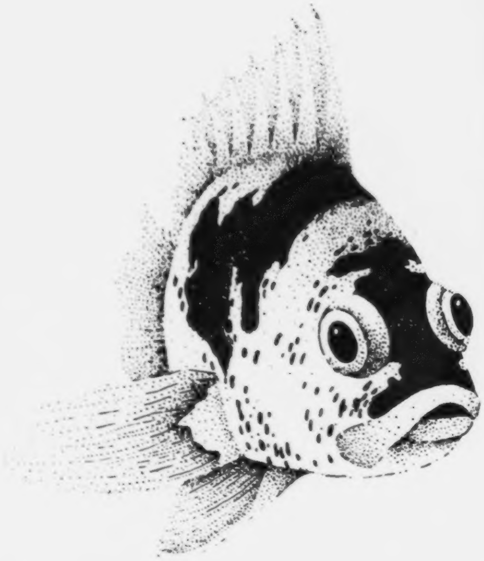

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Center for Environmental Education, Inc., Washington, D.C.

Published by
The Center for Environmental Education
624 9th Street NW
Washington, D.C. 20001

With partial funding from
U.S. Department of Commerce
National Oceanic and
Atmospheric Administration
Sanctuaries Programs Division
(NA82AAA04132)

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ISBN: 0-961-5294-1-5

Designed by Becker/Hockfield Design Associates
Printed in the United States of America

The world below the brine,
Forests at the bottom of the sea, the branches and leaves,
Sea-lettuce, vast lichens, strange flowers and seeds, the thick tangle, openings, and pink turf
Different colors, pale gray and green, purple, white, and gold, the play of light through the water,
Dumb swimmers there among the rocks, coral, gluten, grass, rushes, and the aliment of the swimmers,
Sluggish existences grazing there suspended, or slowly crawling close to the bottom,
The sperm-whale at the surface blowing air and spray, or disporting with his flukes,
The leaden-eyed shark, the walrus, the turtle, the hairy sea-leopard, and the sting-ray,
Passions there, wars, pursuits, tribes, sight in those ocean-depths, breathing that thick-breathing air, as so many do
The change thence to the sight here, and to the subtle air breathed by beings like us who walk this sphere,
The change onward from ours to that of beings who walk other spheres.

Walt Whitman

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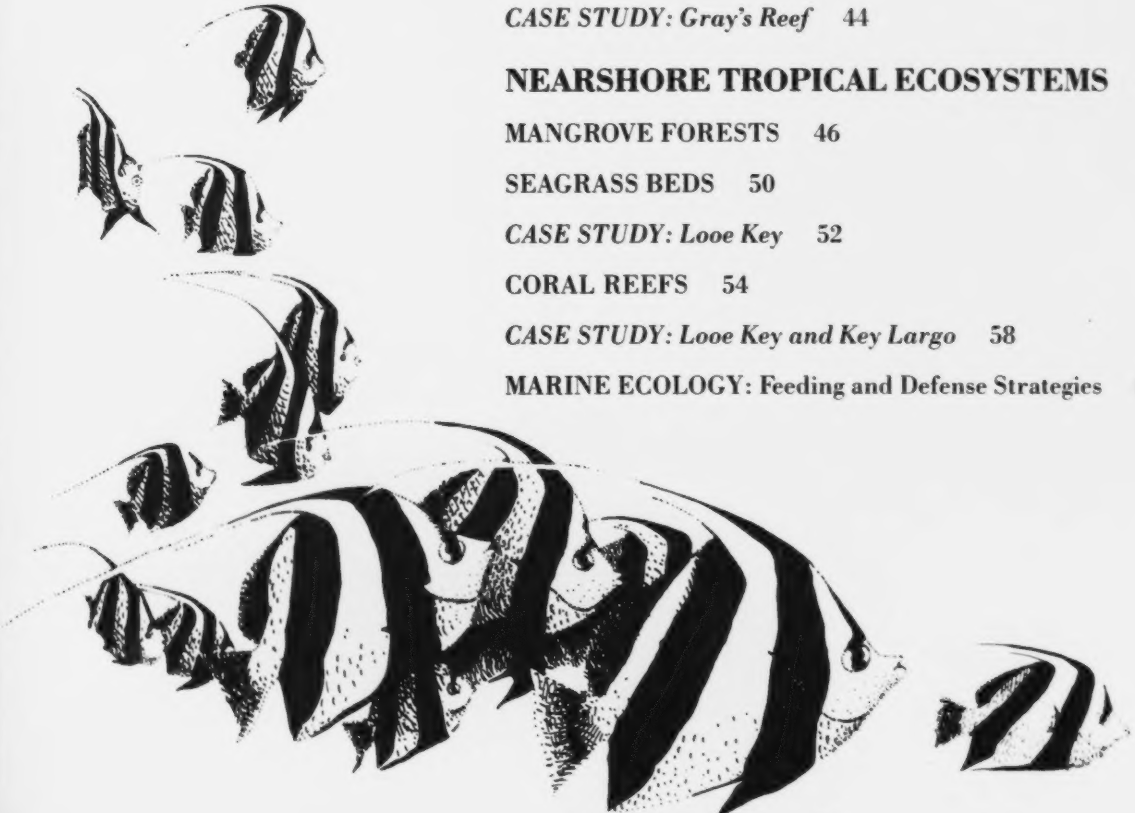

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PREFACE

Americans have spent most of their history looking to the land beyond the horizon for adventure and growth. When Meriwether Lewis and William Clark gazed with awe on the Pacific Ocean, they defined boundaries of our country which were to serve for many years. Much of the westward expansion of the United States was by land. But at the same time the United States expanded its wealth and commerce by sea. By the end of the nineteenth century the United States had become a major ocean power.

Today we can say more strongly than ever that the United States is an ocean nation. While most Americans know that the contiguous United States measures about 3,000 miles across its breadth, few know that our country has a tidal shoreline of over 88,000 miles. With the recent extension of U.S. jurisdiction out to 200 miles offshore, we have over 2.2 million square miles of ocean under our direct economic control.

Americans look ever more to the sea for commerce, food, defense, and recreation. Particularly since World War II, people have been increasingly drawn to the coastline. Now over half our population lives within 50 miles of the coast. Yet most of us know very little about the oceans, its inhabitants, and the processes occurring there.

This book is for people who want to know more about the oceans. It is a book about some of the marine ecosystems of our country—an exploration of the relationships between life in the sea and the energy, chemistry, and physical processes of the sea itself. Just as our nation is blessed with almost every kind of terrestrial landform and ecosystem, from rain forests to alpine meadows, so do the oceans surrounding our shores include ecosystems as diverse as coral reefs and Arctic boulder patches.

Readers of this book need have no special knowledge of the sea nor of biology. All that is needed is curiosity. The book combines three kinds of discussion. The main text of the book describes individual marine ecosystems, such as kelp beds and coral reefs. Accompanying this text are discussions of some of the basic ecological principles found operating in these and other ecosystems. Finally, examples of research conducted in specific marine areas are included to illustrate how scientists go about uncovering the secrets of life in the oceans. We have chosen to illustrate a number of these marine ecosystems with examples drawn from special marine areas set aside by the federal government to conserve and protect fragile living resources. These areas are part of the National Marine Sanctuary Program. This program is an important tool for conservation of selected marine areas in the United States, and is creating a legacy of the best of the nation's natural marine heritage.

To this day, some controversy exists as to whether there is one ocean or several. In this book we have foregone the somewhat romantic notion of one ocean and refer throughout to oceans. Indeed, to forget this would be to ignore part of the complexity of the marine world.

The authors are indebted to a number of people who have made the writing of this book a fascinating adventure of its own. To Carroll Curtis, Research Coordinator of the National Marine Sanctuary Program, we express our deepest gratitude for her continuing encouragement and forbearance during this long project. Other staff at the Sanctuary Programs Division have provided us with valuable advice on the presentation of the material in this book.

The text would be impenetrable were it not for Mary Beath, whose illustrations grace the following pages, and Barbara Hockfield, whose sense for design creates a genial context for the discussions. Judy Hinds improved the text immeasurably by applying her fine sense of English composition to our original overwritten manuscript.

To James A. Bohnsack, Gordon Chan, Doug DeMaster, John Grant, Fred Grasle, Burr Heneman, Walter C. Jaap, Ariel Lugo, Jack Musiak, Nick Nicholson, William Odum, Robert W. Schmieder, Frederick T. Short, Alina Szmant-Froelich, Bill Thomas, Bob Van Dolah, and Joseph C. Zieman, who graciously reviewed sections of the manuscript for accuracy, we are particularly appreciative. Elliott A. Norse provided us with valuable advice in the original conceptualization of the book and spurred us on to plunge into some of the less familiar but fascinating areas of marine ecology.

Donald Chabot, as an intern at the Center for Environmental Education, summarized research conducted in the seven National Marine Sanctuaries.

We owe a debt of special appreciation to John J. Domont and the Sanctuary Programs Division, whose support made this project possible.

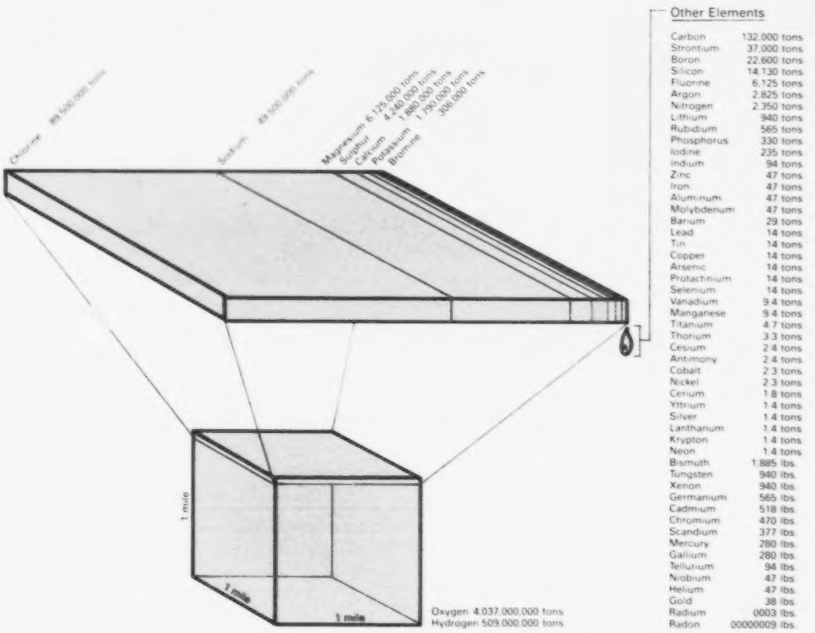
Michael Weber
Richard Tinney
Center for Environmental Education
Washington, D.C.

INTRODUCTION

In the late 1960's and early 1970's astronauts on the moon saw clearly what no one had observed so well or so dramatically before—that the earth is a water planet: the interconnected waters of the oceans cover over 70 percent of the earth's surface. The Pacific Ocean alone is 25 percent larger than all of the world's land surface combined. The oceans occupy an enormous volume of over 300 million cubic miles. The average depth of the oceans is over two miles, with the greatest known depth being just over seven miles in the Marianas Deep of the western Pacific. If the tallest peak on land, the 29,028 foot Mt. Everest, were sunk in this trench, its peak would still be beneath 8,000 feet of water. In fact, if the earth's surface were perfectly smooth, with no mountain peaks or ocean basins, it would be completely covered with water to a depth of 12,000 feet.

The oceans contain over 97 percent of all the water on the earth, with most of the remainder being locked in the polar icecaps. There is much more to sea water than hydrogen and oxygen. Sea water holds a great amount of dissolved gases and minerals in solution. A cubic mile of sea water contains about 90 million tons of chlorine, almost 50 million tons of sodium, and over 6 million tons of magnesium, among other mineral elements ***(Figure 1)***.

Figure 1: Seawater contains many more elements than hydrogen and oxygen.



Scientists believe that the oceans formed over a period of millions of years as the continents were pushed apart by great rifts in the earth's surface. Surprisingly, the water of the oceans, and some of the life forms in it, are older than the sea floor itself. As the earth cooled in the first years of its existence, water vapor in the atmosphere condensed and rained down upon the earth. Over millions of years, more and more water vapor was added to the atmosphere as volcanoes erupted and sent great plumes of gases, including steam, into the air. Slowly, water accumulated on the earth's surface. At the same time, the earth's surface was constantly changing. Volcanic activity pushed rock from the center of the earth to the surface where it formed vast plates of new crust. Older crust was destroyed at places where a crustal new plate was forced over it.

Over the millenia, life proliferated in the oceans. Amazingly, many species that developed hundreds of millions of years ago, such as sharks, exist today. In fact, the oceans teem with "living fossils"—plants and animals which evolved eons ago and remain suitably adapted to the present environment. So agreeable are the oceans to life that all ocean waters, no matter their depth, darkness, or temperature, support some kinds of plants or animals, sometimes in astonishing variety and numbers. Groups of animals such as fishes, seabirds, marine mammals, molluscs (clams and snails), crustaceans (lobsters, shrimps, crabs, and barnacles), and echinoderms (starfishes and sea urchins) exist in a profusion of forms and numbers in all the parts of the oceans. Interestingly, insects are almost completely absent from the oceans.

Humans began harvesting the oceans' plant and animal bounty before the beginning of recorded time, using marine resources for food, clothing, and art objects. As cultures became more sophisticated, they also became more daring in their exploitation and exploration of the sea. Around 2,000 B.C., Egyptian voyagers were travelling as far as Arabia and Somalia. A thousand years later the Phoenecians were exploring the Mediterranean, the Red Sea, the Gulf of Aden, the Persian Gulf, and the Arabian Sea, venturing at least as far as India. They also sailed through the Straits of Gibraltar, discovering the Canary Islands in the Atlantic. By 325 B.C., Aristotle was operating a marine biological station on the island of Lesbos in the Mediterranean Sea. In the meantime, the people of the Pacific independently developed their own navigation techniques, which included star charts and knowledge of currents and bird migration ***(Figure 2)***.

With the European discovery of the New World, marine science and marine industry took a great

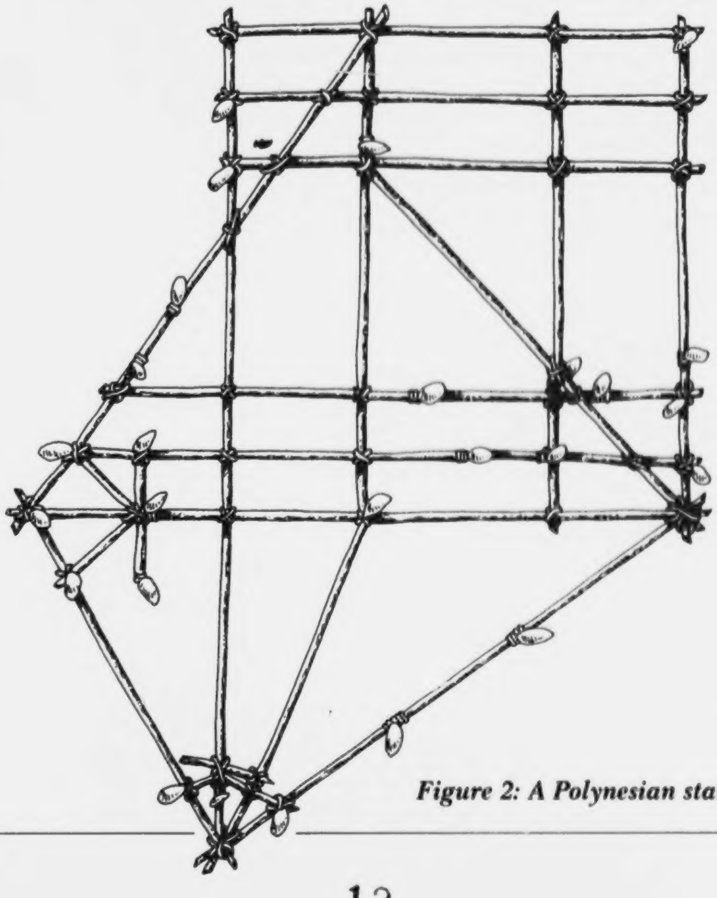


Figure 2: A Polynesian star map.

leap forward. The "age of navigation" dawned and the oceans became rivers of commerce. The wealth of the colonies in the New World and the Far East was exchanged for manufactured goods from the motherlands.

Together with the development of trade came increased knowledge. Modern ocean science can be said to have started with Portugese and Spanish navigators beginning in the fifteenth century. As they ventured farther and farther, they discovered many of the ocean's major currents. They also needed an accurate means of determining their locations. So, over many years, the science of celestial navigation developed.

In the United States, ocean science began with Benjamin Franklin's charting of the Atlantic Ocean's Gulf Stream. Knowledge of ocean currents advanced again in 1855 when Matthew Fontaine Maury, a U.S. Navy navigator and Superintendent of the Navy's Depot of Charts and Instruments, published his *Physical Geography of the Sea,* the first major oceanography text.

About the same time, marine biologists were unlocking some of the secrets of life in the sea. One of the earliest voyages of biological discovery was the 1831-1836 expedition of the H.M.S. *Beagle* on which Charles Darwin gathered data that led him to his theories of natural selection and evolution. He also developed a theory of the origin of coral atolls, a theory still widely accepted.

Perhaps the greatest oceanographic expedition ever undertaken was the 1872-1876 voyage of the H.M.S. *Challenger.* On a winding, 70,000 nautical mile voyage around the world, the *Challenger* expedition gathered information on the physics, chemistry, geology, and biology of the oceans. The results of the voyage filled 50 large books and took 23 years to publish.

As in the past, modern use of the oceans depends on an understanding of the oceans and all that is happening in them. Fisheries, transoceanic cables, shipping, oil drilling, and all the other commercial uses of the sea require a thorough knowledge of at least some aspect of marine science. The same is true of military uses of the sea and even of some recreational uses such as scuba diving and sailing.

Figure 3: Manned submersible vehicles, such as Alvin, have enabled scientists to view previously unsurveyed marine areas, such as hydrothermal vents, in the deep ocean. Remote-controlled vehicles now allow scientists to explore the depths of the oceans from surface ships.

With satellites, remotely-piloted submarines, and sophisticated electronics, ocean science has entered the high-technology era ***(Figure 3)***. Science continues to uncover new ocean wonders that never cease to amaze. Field scientists on the west coast of the United States, for instance, discovered several new species of marine plants and animals in an area near

San Francisco after a single week of scuba diving. As we learn more about the oceans, these discoveries seem to come faster and with more dazzling revelations. Even with all we think we know about the oceans, the oceans are still a source of mystery.

Today, the oceans are more important than ever before. In the United States alone, five million barrels of oil arrive each day by ship from overseas. Another million barrels are produced from our country's offshore oil fields. Fishing also is a multi-billion dollar industry in the United States, directly employing over a quarter of a million people. Thousands of ships call at U.S. ports, carrying billions of tons of goods.

Our industrialized civilization relies on the ocean in other ways. Every year hundreds of millions of tons of municipal and industrial wastes are disposed in the oceans off the United States. These wastes include sewage, toxic chemicals, petroleum products, and pesticides. Unfortunately, the wastes sometimes are dumped where they can do the most damage: near the rich coastal fishing grounds and coastal urban areas. And as our nation's population grows our waste products increase.

More happily, the oceans offer some of the greatest recreational and wildlife habitat resources the country has. Today, more than 120 million Americans live within 50 miles of the oceans. Millions more visit the sea at some time in their lives. In an average year, about 20 million of us go ocean fishing. About 30 million people go clamming, crabbing and shell collecting each year. Millions more go to the oceans to observe or photograph wildlife, to go boating or sailing, to swim at the beach, to go diving or surfing, or to camp.

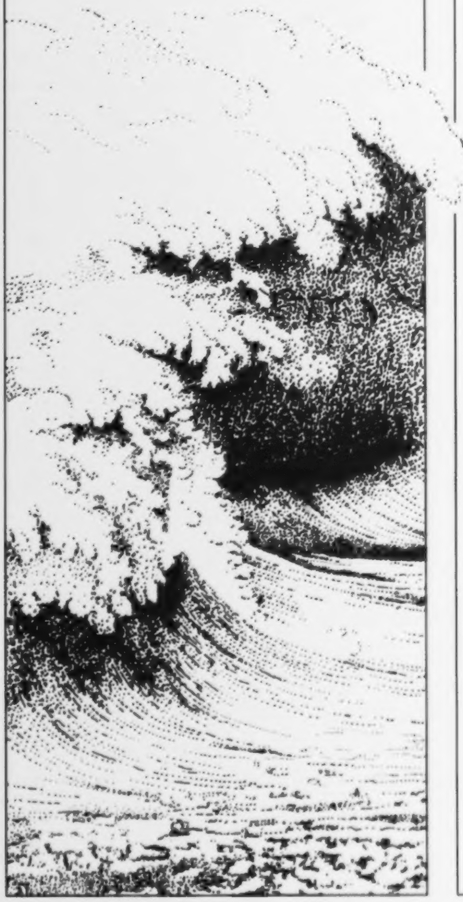
The United States has a proud tradition of protecting outstanding natural areas. Even when the American West was still a frontier, a small group of Americans recognized that some of the nation's outstanding natural areas would be lost unless dramatic action were taken. Thus, just over one hundred years ago, the natural wonders of Yellowstone were set aside as a national park. The visionary founders of the first national parks had no idea how wise an investment they had made for the nation: each year millions of Americans find unique recreational opportunities in our national parks. At the same time, the national parks conserve some of our outstanding wild areas and wildlife habitats. It is no wonder that our national parks system has been emulated by nations around the world.

Our attempts to conserve part of our nation's marine heritage, as spectacular as our terrestrial heritage, are at the same stage that our national park system was in the late nineteenth century. Only in 1972 did our nation begin to conserve nationally significant marine areas systematically. In that year the United States Congress passed a law, the Marine Protection, Research and Sanctuaries Act, which authorized the designation of National Marine Sanctuaries for their "conservation, recreational, ecological, or esthetic values." Legislators explained that no law then on the books met the need to protect the living resources of the sea from intrusive human activities.

The National Marine Sanctuary Program seeks to conserve outstanding marine areas for future generations by managing human activities that may damage their integrity. Through research and educational activities the program also seeks to increase scientific understanding of marine ecosystems and to inform the public about the wise use of marine resources. In the future, the pressures on our marine resources will mount and the need for an informed citizenry will become even more pronounced. The National Marine Sanctuary Program is making its own unique contribution to insuring that this need is met.

This book is meant to increase the appreciation of the oceans and their inhabitants among visitors to National Marine Sanctuaries and among other people who are interested in the oceans. In the following pages we will take you on a journey that will help you understand differences and similarities between the life of the oceans and our own. And, perhaps, when you next gaze beyond the water's edge, the oceans will reveal a new meaning to you because you have come with a new understanding.

A SAMPLING OF MARINE ECOSYSTEMS



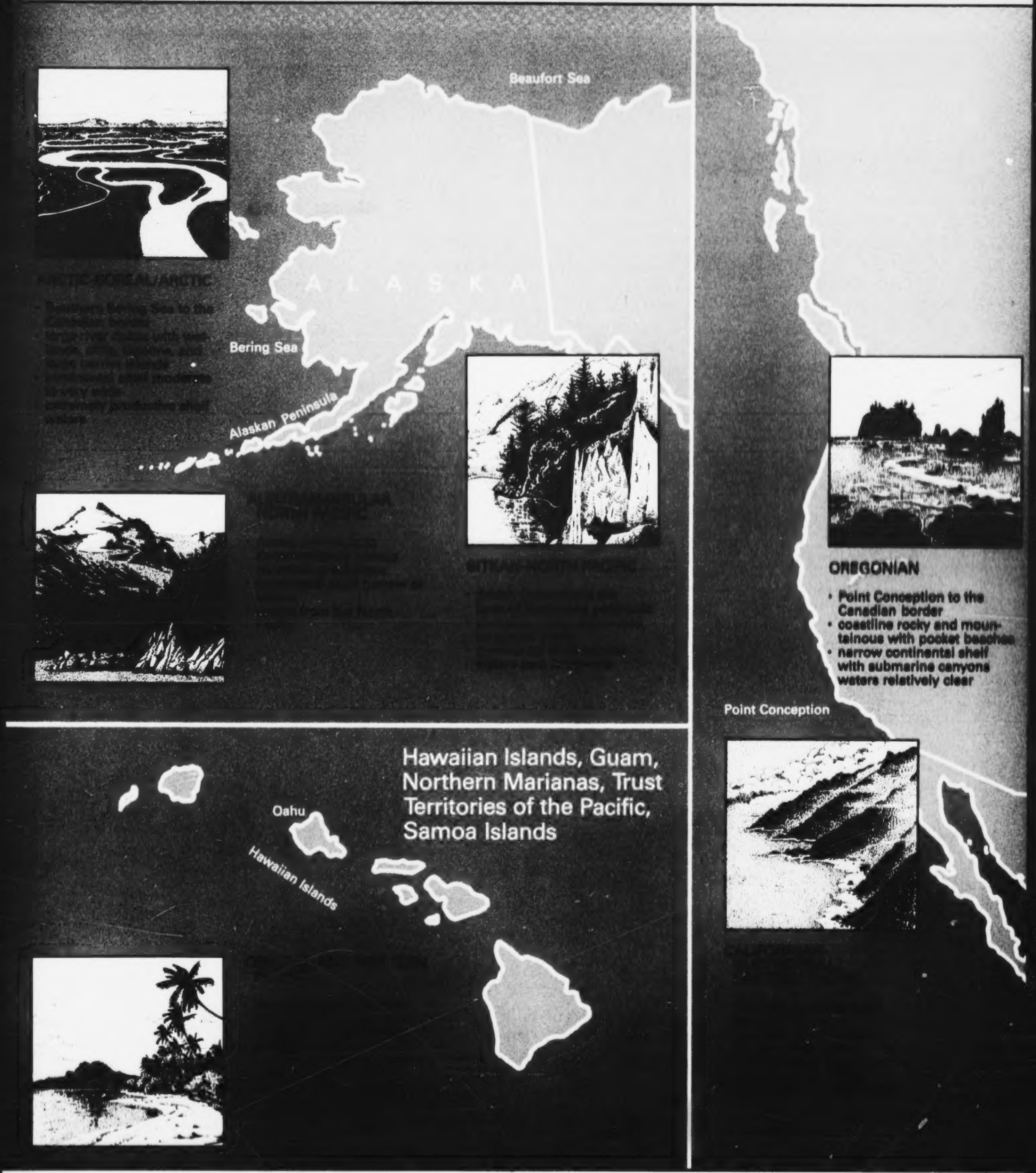
Many years ago the American naturalist and conservationist John Muir remarked that when one looked at the natural world one saw that everything was connected to everything else. Muir's insight expresses a principle that many others have come to recognize. It forms the basis of the modern science of ecology which explores the pervasive interrelationships among all things on earth. From ecology, we are beginning to learn that we can never affect just one thing; whatever we do to one element in the natural world will have an effect on other elements.

Ecology is the scientific study of interactions in natural systems that determine the distribution and abundance of plants and animals. A system is a collection of parts or events that can be seen as a single whole thing because of the interdependence and interaction of those parts or events. For instance, a ship is composed of many parts, such as an engine, fuel tanks, a radio room, a rudder, and propellers. Taken together, these parts function as a transportation system in which the parts normally interact in a predictable fashion.

Natural systems are sometimes called ecosystems. An ecosystem is defined as a unit that includes all of the organisms in an area interacting with their physical environment. The factors operating in an ecosystem are divided into biotic (bios=living) and abiotic (a=not) elements. Biotic factors include the plant and animal life of an ecosystem. Abiotic factors include minerals, temperature, pressure, and exposure to sunlight, among other things.

Ecosystems can be as large as the earth itself or as small as a tidepool. The biotic and abiotic factors in ecosystems can also vary considerably. An oak forest, a swamp bog, an alpine meadow, a trout pond—each can be called an ecosystem. Each has a distinctive grouping of plants and animals that live and interact with their environment and with each other. Each has finely-tuned machinery to capture, transfer, and cycle the energy and matter that living organisms depend upon for life.

The oceans include a startling array of ecosystems, and the United States is blessed with a wealth of living marine resources and marine environments. Scientists believe that off the coasts of the United States, from the frigid ice-scoured waters of the Arctic Ocean to the tropical reefs of the Florida Keys, the West Indies, and the Pacific islands, there are more kinds of marine plants and animals in more kinds of marine habitats than are found off any other country in the world ***(Figure 4)***.



ARCTIC-BOREAL/ARCTIC

- Southern Bering Sea to the Canadian border
- large river deltas with wetlands, spits, lagoons, and [illegible] barrier islands
- continental shelf moderate to very wide
- extremely productive shelf waters

ALEUTIAN INSULAR/ NORTH PACIFIC

[illegible]

SITKAN-NORTH PACIFIC

[illegible]

OREGONIAN

- Point Conception to the Canadian border
- coastline rocky and mountainous with pocket beaches
- narrow continental shelf with submarine canyons waters relatively clear

CALIFORNIAN

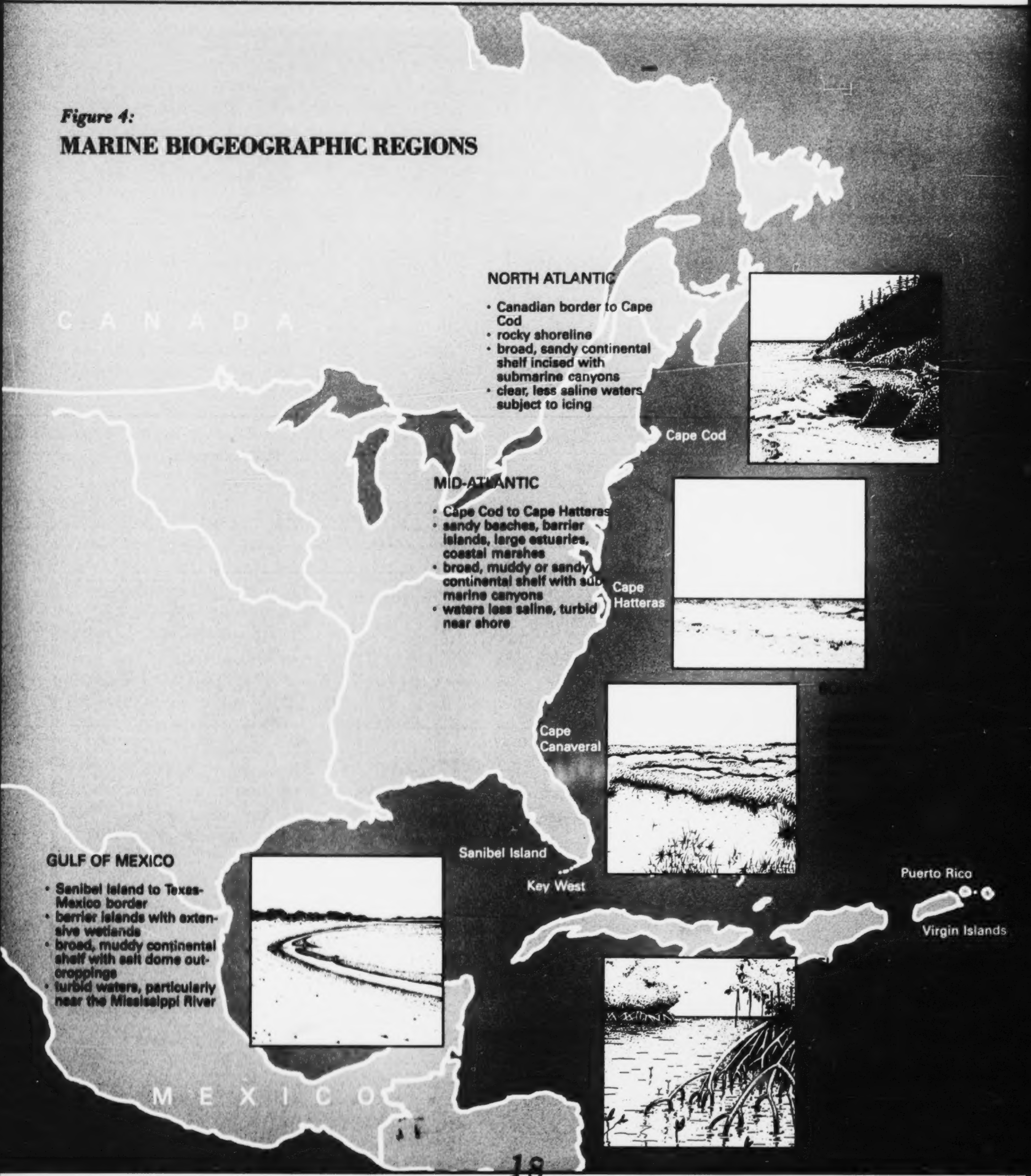
[illegible]

Hawaiian Islands, Guam, Northern Marianas, Trust Territories of the Pacific, Samoa Islands

[illegible]

Figure 4:

MARINE BIOGEOGRAPHIC REGIONS



NORTH ATLANTIC

- Canadian border to Cape Cod
- rocky shoreline
- broad, sandy continental shelf incised with submarine canyons
- clear, less saline waters subject to icing

MID-ATLANTIC

- Cape Cod to Cape Hatteras
- sandy beaches, barrier islands, large estuaries, coastal marshes
- broad, muddy or sandy continental shelf with submarine canyons
- waters less saline, turbid near shore

GULF OF MEXICO

- Sanibel Island to Texas-Mexico border
- barrier islands with extensive wetlands
- broad, muddy continental shelf with salt dome outcroppings
- turbid waters, particularly near the Mississippi River

OFFSHORE OPEN WATER AND BENTHIC ECOSYSTEMS

Due largely to the inaccessibility of all but the shallowest areas of the oceans, we know relatively little about open ocean and benthic (=occurring on the bottom) ecosystems. As it is, the accelerating study of these extreme marine environments regularly reveals new and unexpected aspects of life in the oceans. Oil company scientists, for example, found over 15 apparently new species of plants and animals while performing surveys off the coast of central California in 1982. So little is known about the animals and plants of the sea floor that the scientists were unable to say whether any of the new species were rare or unusual – only that no one had ever seen them before.

Even the shape of the ocean bottom was all but unknown until recently. Concerted efforts at mapping the ocean have shown us that the topography of the ocean floor is even more spectacular than that of the land. The mountain ranges and canyons of the oceans are higher, deeper and larger than those on land. The seaward edge of the underwater continental shelf is scored in many places with deep submarine canyons. Both the continental shelf and the seafloor sloping to the deep ocean plain may be rocky, gravelly, sandy, or muddy. Each type of surface presents its own challenges to organisms living there.

Many of the same challenges are found in the water itself, for the physical environment of the open ocean is by no means uniform. Differences in water temperature, salinity (sali=salt), and pressure create barriers between the waters at different depths.

The topography of the seafloor, together with currents and other environmental factors, creates a wide variety of ecosystems in offshore waters. On the following pages, five of the more interesting of these are presented.

Upwelling

The most widely distributed ecosystem in the marine waters off the United States is that of the open water itself, away from the rocks, sand, and mud of the shore, away from attached seaweeds and coral reefs. These open waters, also called pelagic waters, are much different from coastal waters. The most obvious difference is that the plants and animals of pelagic waters have no substrate or bottom to which they may attach themselves. Instead they swim or drift unattached. There are more subtle differences as well. These offshore waters do not receive nutrients from land runoff and rivers. As a result, open ocean waters are generally less productive than the nutrient-rich waters near the shore.

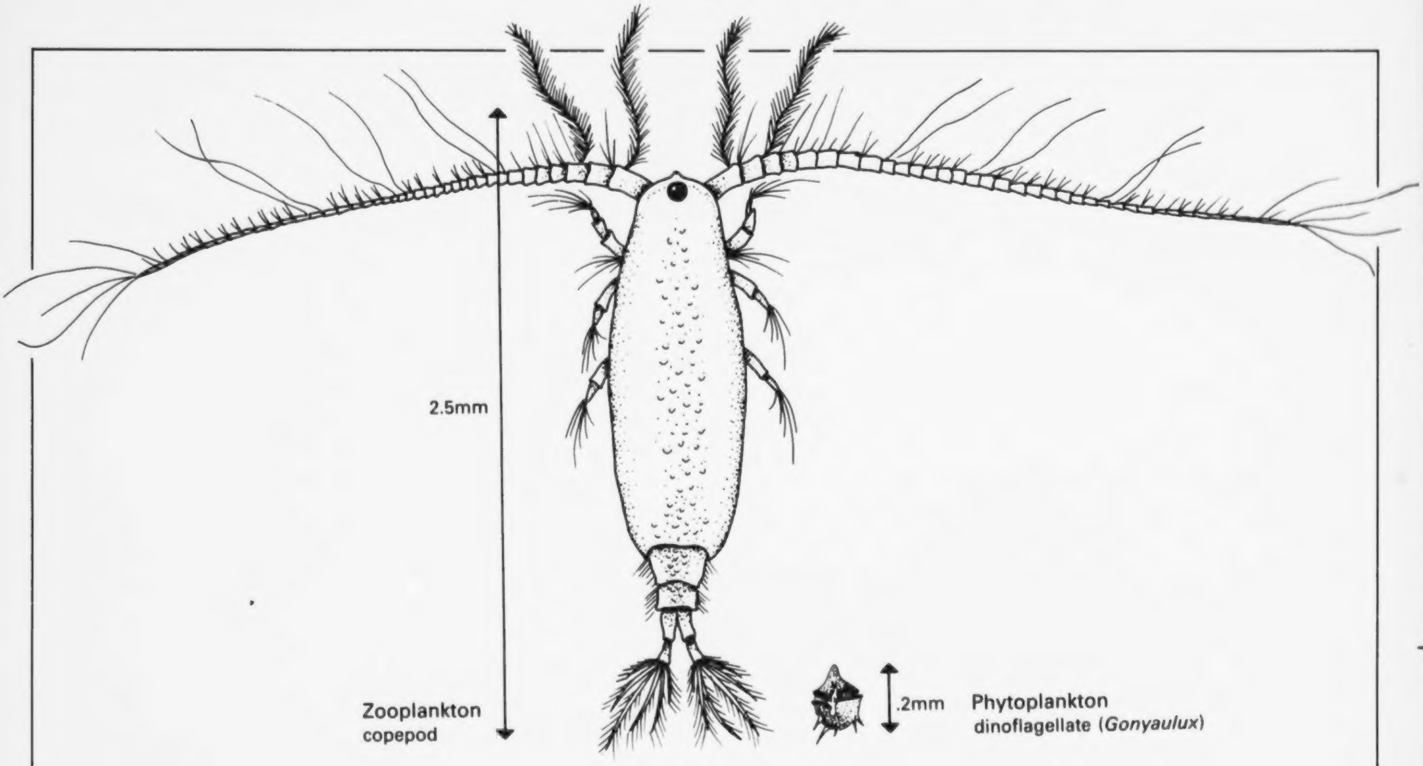


Figure 5: As phytoplankton blooms, populations of zooplankton increase rapidly as well. As the types of nutrients available in the water change, the species of phytoplankton will change.

The basis of the open ocean's productivity, as elsewhere in the marine environment, is the great mass of microscopic phytoplankton (phyto=plant, plankton= wandering), the billions and billions of tiny plants that drift in the upper waters of the oceans and use the energy of the sun to produce carbohydrates. Some of the phytoplankton are eaten by zooplankton (zoo= animal), animals not quite as tiny as the phytoplankton ***(Figure 5)***. Some of the zooplankton are destined to stay zooplankton for their entire lives. Other forms of zooplankton, however, are the larval or juvenile forms of much larger animals such as crabs, sardines, mackerels, and anchovies.

When the larval or juvenile forms of these organisms mature, they join the ranks of the nekton (neo=swim), the free-swimming creatures of the sea, or settle to the bottom where they spend the rest of their lives attached to or burrowed into the sea floor. Like the zooplankton, the nekton are consumers. Some of them eat zooplankton, even the young of their own kind; some eat other members of the nekton.

When a member of the nekton dies, it joins the slow rain of other dead animals, plants, and wastes that drifts gradually down to the bottom of the sea. Some of this detritus (detrit=wear off) is consumed as it falls to the bottom. The detritus that reaches the bottom becomes available to benthic animals. Benthic animals never venture far into the realm of the nekton, generally staying on or quite close to the bottom. Some benthic animals, like worms, clams, and brittle stars, spend their entire lives on or just beneath the ocean bottom. Others, such as various fishes, alternately rest on the bottom and swim just above it ***(Figure 6)***.

Where the physical and topographic conditions are right, the deposits of detritus may be lifted to sunny surface waters by the upwelling of bottom waters ***(Figure 7)***. Upwelling occurs predominantly along the west coasts of the continents, where nearshore surface water is pushed offshore by prevailing winds or the rotation of the earth. The displaced nearshore water is replaced by the upwelling deep water.

Compared to the surrounding water, the water coming to the surface in an upwelling is cold and nutrient-rich. The combination of sunlight, favorable temperature, and nourishment results in exceptionally large growths of phytoplankton. In turn, the phytoplankton provides a rich food source for zooplankton. The nutrients in upwelling waters are passed on to other, larger

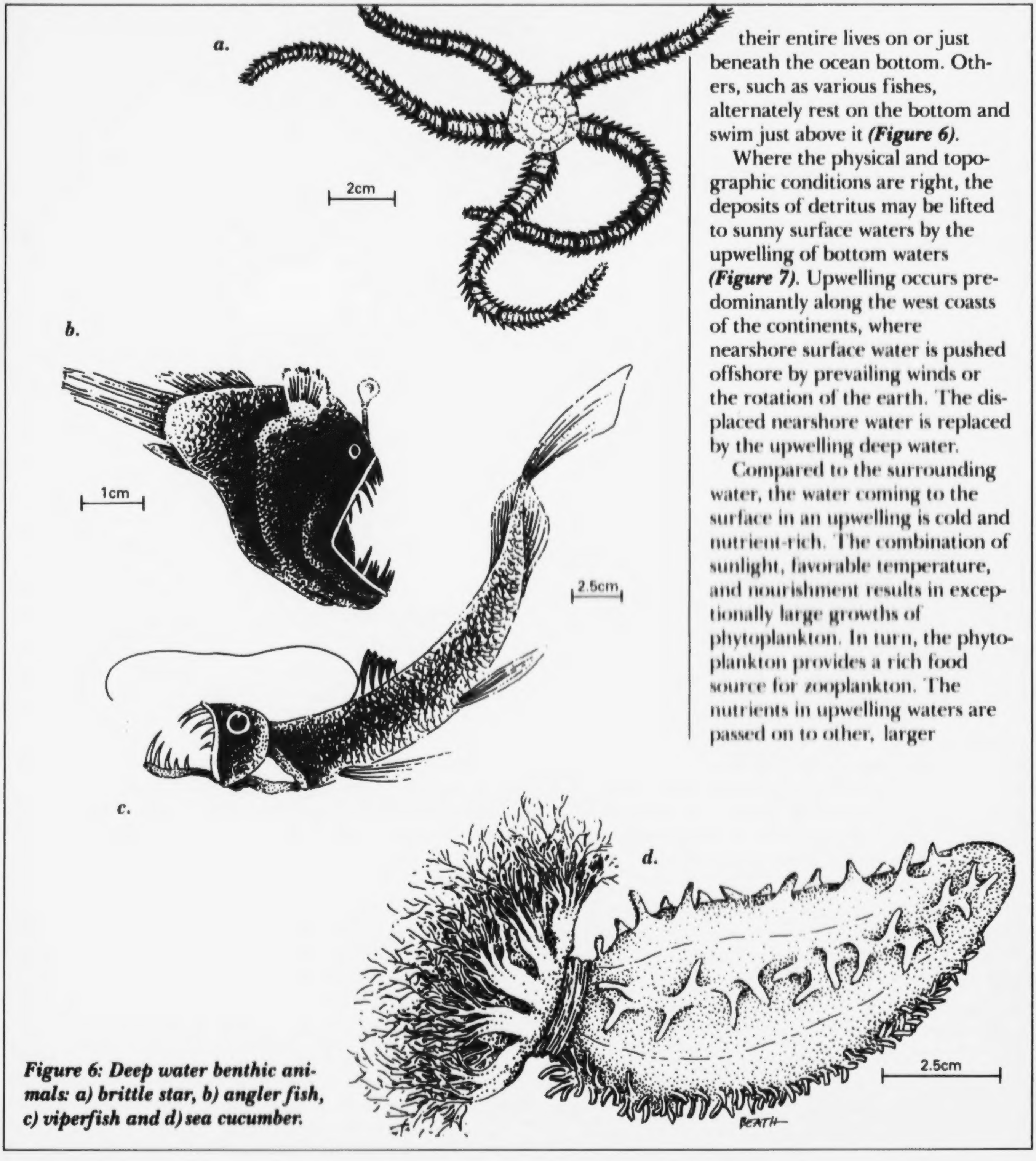


Figure 6: Deep water benthic animals: a) brittle star, b) angler fish, c) viperfish and d) sea cucumber.

animals such as fish in what is one of the most productive marine ecosystems. The abundance of food for fish means also that the predators of fish, such as seals and seabirds, benefit from the upwelling as prey becomes readily available.

Upwelling systems are not constant. Sometimes the changes in upwelling are predictable. An excellent example is the case with the reversal of the currents, which can cause upwelling events, off the west coast of the United States during the winter. During the summer months the coast is cooled by northwest winds and a flow of cold water from the north. Around November, the northwest winds diminish and the cold southward flowing water begins to sink. A thin layer of northward flowing warmer water, usually found at depths lower than 600 feet, moves to the surface and forms a wedge between the coast and the southward flowing currents. The warm wedge of water flows northward. By February and March the northwest winds pick up again, and upwelling returns. So predictable is this cycle that huge commercial fisheries have come to depend upon it.

At other times, the changes in ocean currents are completely unexpected, leading to natural catastrophes. One such change is the irregular occurrence of currents known as El Niño. These are strong warm water currents that displace the normally colder waters and block any upwelling. The nutrient-rich waters of the upwellings, depended upon by creatures at all levels of the food chain, do not appear. Chaos is the result. The effects are readily seen in colonies of seabirds. The normally teeming masses of breeding birds sometimes don't even bother to arrive at the rookeries; those that do often do not breed. The normally swarming colonies are reduced to bedraggled birds unable to find enough food for the few young who hatch.

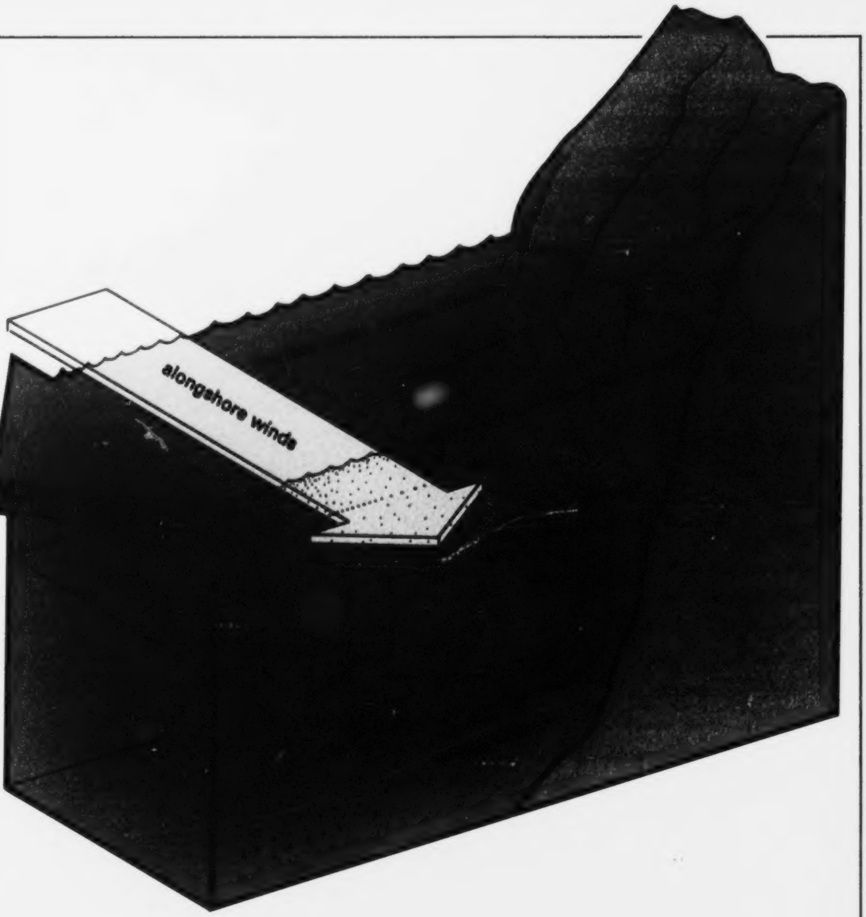


Figure 7: Where conditions are favorable, nutrient-rich deep water may well up to replace surface waters pushed offshore by winds. Areas of frequent upwelling often attract and support large populations of birds, fishes, and marine mammals.

CASE STUDY

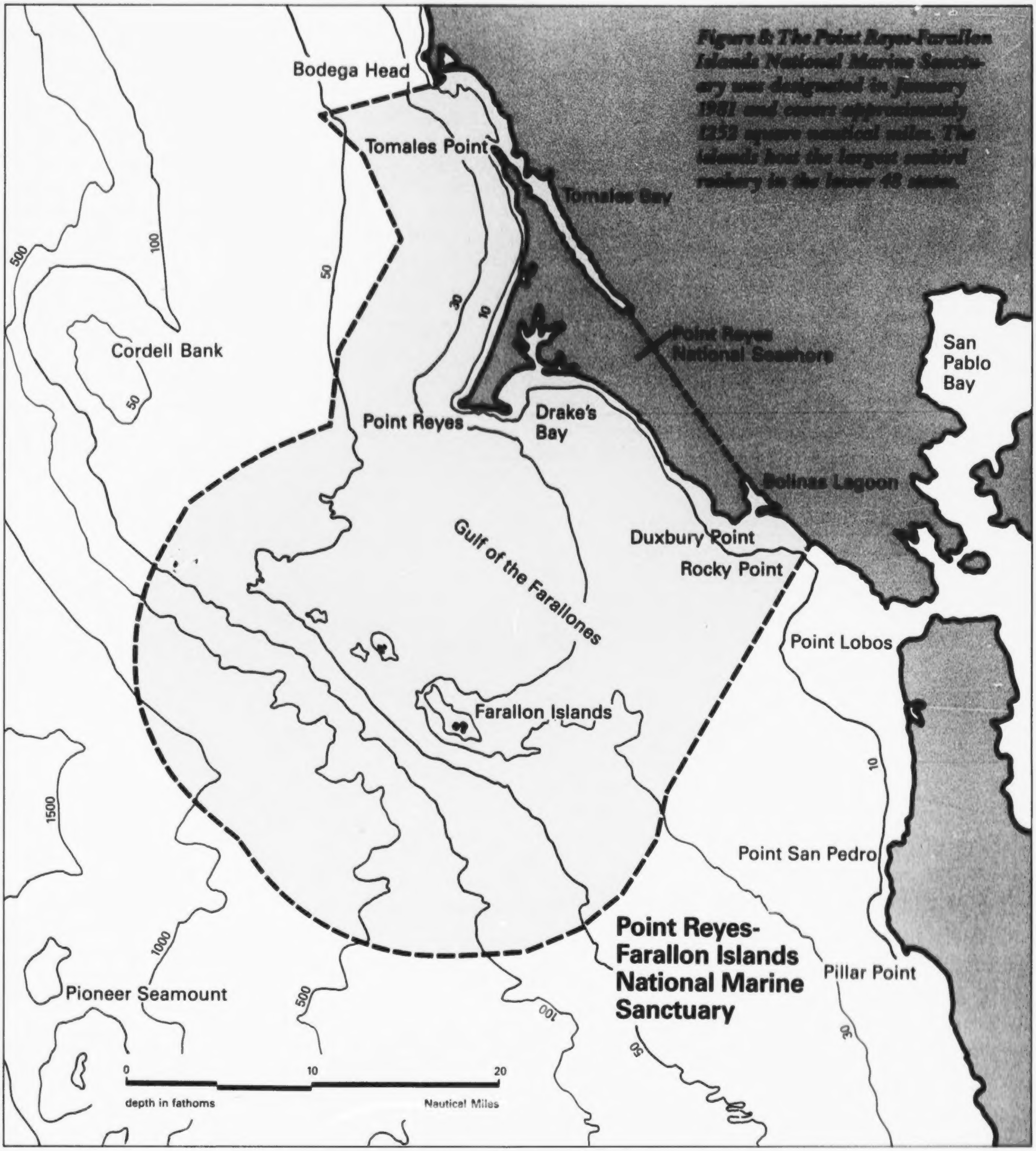
Farallon Islands

The Farallon Islands, 25 miles off the mainland of California near San Francisco and part of the Point Reyes-Farallon Islands National Marine Sanctuary, host one of the most abundant and diverse seabird communities in the United States south of Alaska ***(Figure 8)***. For over ten years scientists have been studying the ecology of twelve marine bird species breeding on the islands. Most of the research effort has focused on ashy storm-petrels, Brandt's and pelagic cormorants, black oystercatchers, western gulls, common murres, pigeon guillemots, and Cassin's auklets. The scientists have also been watching the islands' small and relatively inaccessible populations of double-crested cormorants, tufted puffins, rhinoceros auklets, and Leach's storm-petrels ***(Figure 9)***.

Scientists have noted such things as the dates of the adult birds' arrival on the islands and the times eggs were laid and hatched and the young birds fledged. They have also investigated where the birds go when they leave the islands and how well they survive when away. Scientists have studied how the birds feed, where they feed, how much time they spend feeding, and what they eat. They also gather data on seawater temperature and salinity, two factors which affect the availability of prey species. These last two are collected in order to show the relationship between the physical environment of the feeding areas and the feeding behaviors of the birds.

All of this information is being combined in an analysis of a breeding seabird community's ecology unlike any done before. The most important finding to date is that the great annual variation in the reproductive success of the birds is tied to the productivity of the surrounding waters and the resulting availability of prey. For example, in the winter and spring of 1983, unusually warm sea surface temperatures and a lack of upwelling disrupted the food web of the Farallons. The level of phytoplankton declined sharply and, like a hot air balloon with its burners turned off, the food web collapsed for predators at all levels, including the seabirds. The mortality of seabirds was very high and breeding populations were reduced. Those birds that did breed often did so much later than usual. Chick mortality was high since the adults were unable to feed the chicks or were gone so long looking for food that the chicks were exposed to predators more than in other years. Similar results were seen in the warm water years of 1972 and 1976.

Figure 9: Unlike the feathers of other water birds, cormorants' feathers are not heavily oiled and become waterlogged. It is not unusual to see these excellent divers stretching their wings to dry.

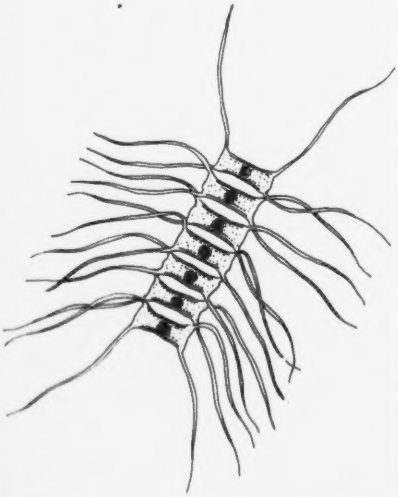


Point Reyes-Farallon Islands National Marine Sanctuary

Figure 8. The Point Reyes-Farallon Islands National Marine Sanctuary was designated in January 1981 and covers approximately 1252 square nautical miles. The islands host the largest seabird rookery in the lower 48 states.

MARINE ECOLOGY

Primary Productivity



Organisms, whether plant or animal, need energy for growth, reproduction, and other physiological processes. The source of almost all energy used by life on earth is the sun. In the oceans, phytoplankton is the primary direct user of the energy of sunlight. Some larger plants, such as blue-green algae, seagrasses, and seaweeds, also capture sunlight. These larger plants, however, play a significant role in maintaining life only in relatively small nearshore areas of the oceans, such as in seagrass and kelp beds.

All of these plants use the energy in sunlight to bind water and carbon dioxide into small packets of stored energy called carbohydrates: the sugars, starches, and oils. In this process, called photosynthesis (phot=light; synthesis=placing together), plants change the energy of sunlight into a form that is usable by other organisms. The rate at which plants fix or change the energy of the sun and make it more generally usable is known as primary productivity. This determines to a very great extent the amount of animal life that can live in an area.

Sunlight is not the only ingredient needed for life in the oceans. Even if there is sufficient sunlight, plants may not grow if certain essential nutrients are not available. For instance, diatoms, a type of phytoplankton, enclose themselves in a shell-like structure made of silica ***(Figure 10)***. Diatoms require silica the same way we require calcium for our bones. Water with less silica in it will allow fewer diatoms to grow. In such a situation, the nutrient salt silica is called a limiting factor on the growth of diatoms. Phosphates and nitrates are among the other nutrients that are required for the growth of phytoplankton.

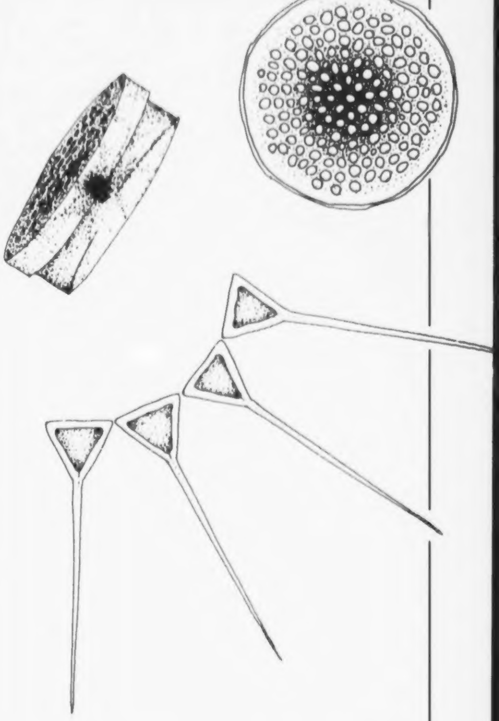


Figure 10: Like snowflakes, the microscopic plants called diatoms take on fantastic forms. Deposits of dead diatoms several hundred meters thick cover some areas of the ocean floor.

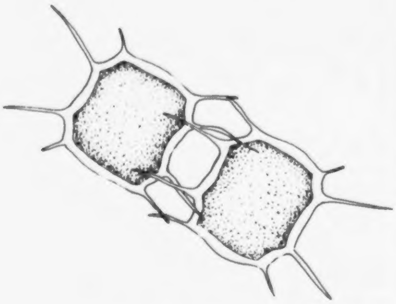
While the salinity of the ocean is fairly constant at about 35 parts of salt per thousand parts of sea water, the availability of the nutrient salts upon which plant growth depends may vary. In many nearshore areas, for instance, necessary nutrient salts may be at very low concentrations for much of the year. During the rainy season, however, runoff from the land may increase significantly the availability of nutrients. Where there is intensive use of nitrogen- and phosphorus-based fertilizers, large amounts of nitrates and phosphates may be washed into the sea, creating unusual blooms of phytoplankton. These blooms may rob other marine plants and animals of the sunlight and oxygen they require, and thereby decrease the normal variety of life in that area.

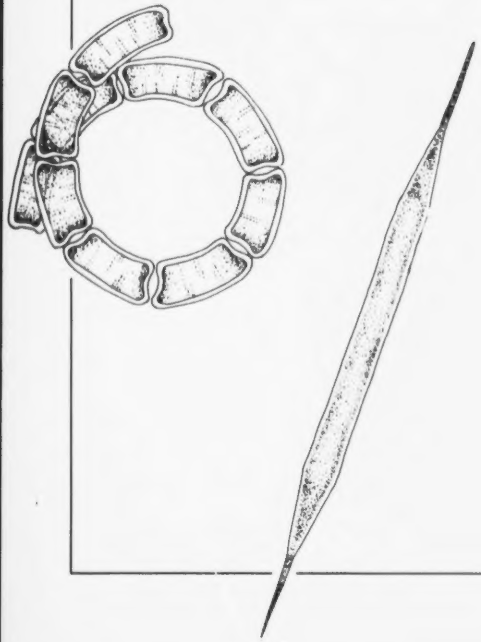
Some of the phytoplankton and detritus from other organisms sinks to the ocean bottom, providing nutrients for bacteria and other benthic organisms. Additionally, some of the remaining nitrates, phosphates, and other nutrients may be brought to the surface by ocean currents. When this occurs, these nutrients become available once again to the phytoplankton in surface waters and the whole cycle begins again.

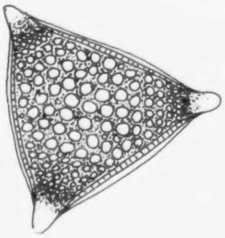
Life in the oceans also requires oxygen in order to use the energy stored in carbohydrates. Oxygen dissolves into water easily, especially where the surface is stirred by the wind or waves. During photosynthesis, plants release oxygen into the water. Where there has been great plant growth, the water is likely to be saturated with oxygen. Also, cold water can hold more oxygen than warm water; as a result, deep water and polar water is often very rich in oxygen.

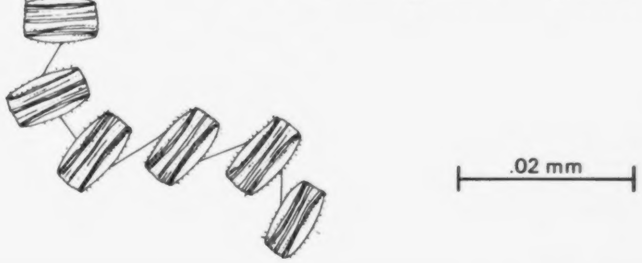
Plants in the oceans also need carbon dioxide for photosynthesis, which is found both in solid and gaseous forms. When plants and animals unlock the energy in carbohydrates through respiration, they produce carbon dioxide that dissolves in the waters of the ocean. Carbon dioxide from the atmosphere is also dissolved in water.

Although photosynthesis by green plants is responsible for the greatest production of the complex energy-laden compounds on which life depends, such compounds may be generated in other ways. Photosynthetic bacteria use hydrogen sulfide or organic compounds in fashioning packets of energy. Other bacteria do not even require light but create energy-laden compounds by









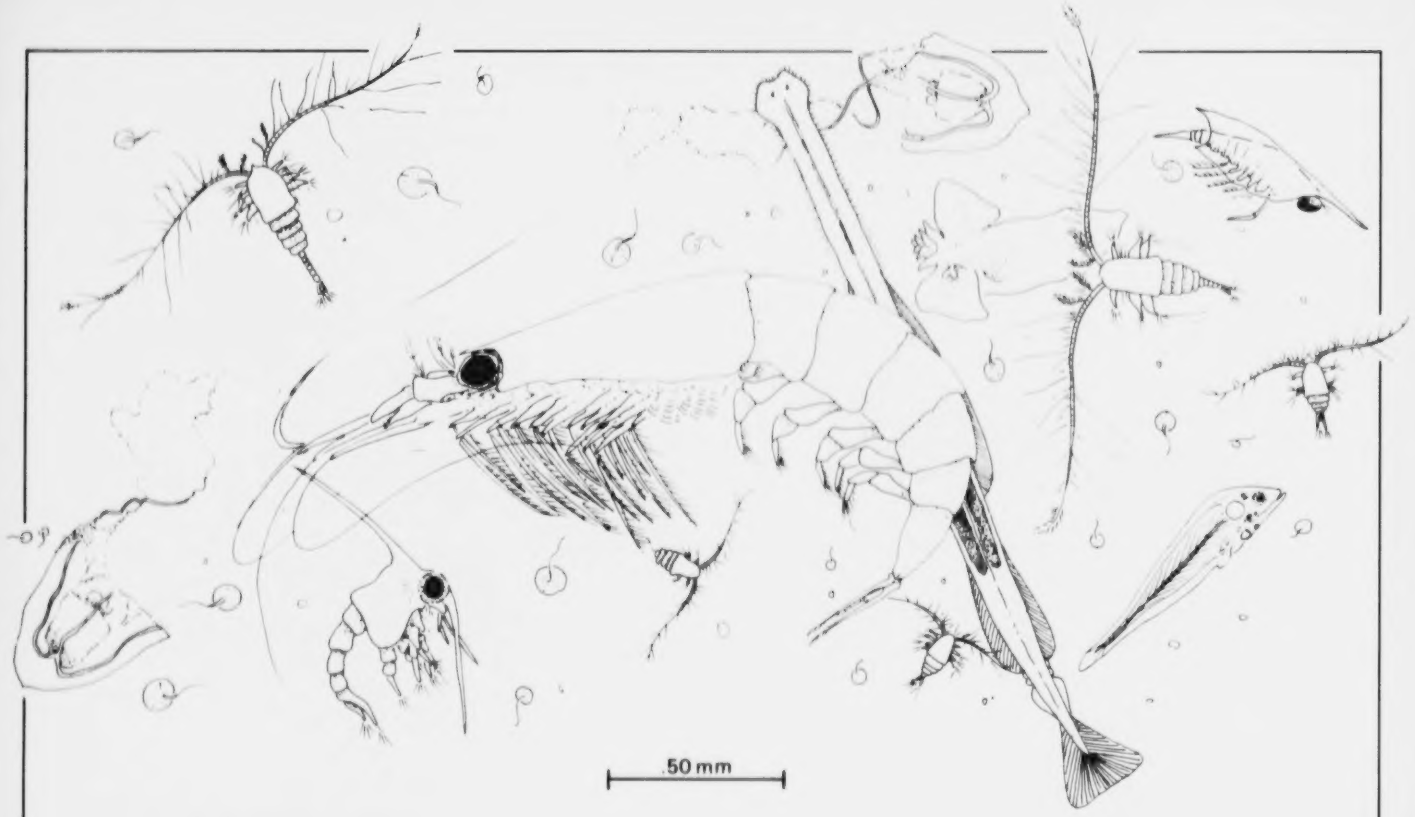


Figure 11: N.J. Berrill has calculated that to feel full a humpback whale may have to eat a ton of herring (about five thousand fish). These fish have in turn fed on zooplankton each of which has fed on as many as 130,000 diatoms (a kind of phytoplankton). Thus, a single meal for a humpback whale may represent more than 400 billion diatoms.

the chemical oxidation of simple inorganic compounds, such as ammonia or sulfide. In this process, called chemosynthesis, bacteria that can live deep in sediments make mineral compounds such as nitrate available to other organisms. Without these bacteria, the minerals and the energy trapped in sediments would be lost to the living creatures that depend upon them.

Because plants convert the energy of the sun into a form which can be used by other organisms, they are called primary producers. These producers are preyed upon by a variety of primary herbivorous consumers (herb=grass, vor=eat), including zooplankton ***(Figure 11).*** Like all other animals in the oceans, zooplankton are not able to capture the energy of sunlight directly and must depend upon plants to do this for them. The zooplankton may include small, shrimp-like creatures and the larval forms of fishes and other marine animals. The herbivorous primary consumers are then preyed upon by secondary carnivorous consumers (carn=flesh), such as most fishes. Some of the secondary carnivorous consumers may be fed upon by tertiary consumers, such as wading birds. Finally, decomposers, such as bacteria and fungi, feed on detritus from these animals, completing this food chain ***(Figure12).***

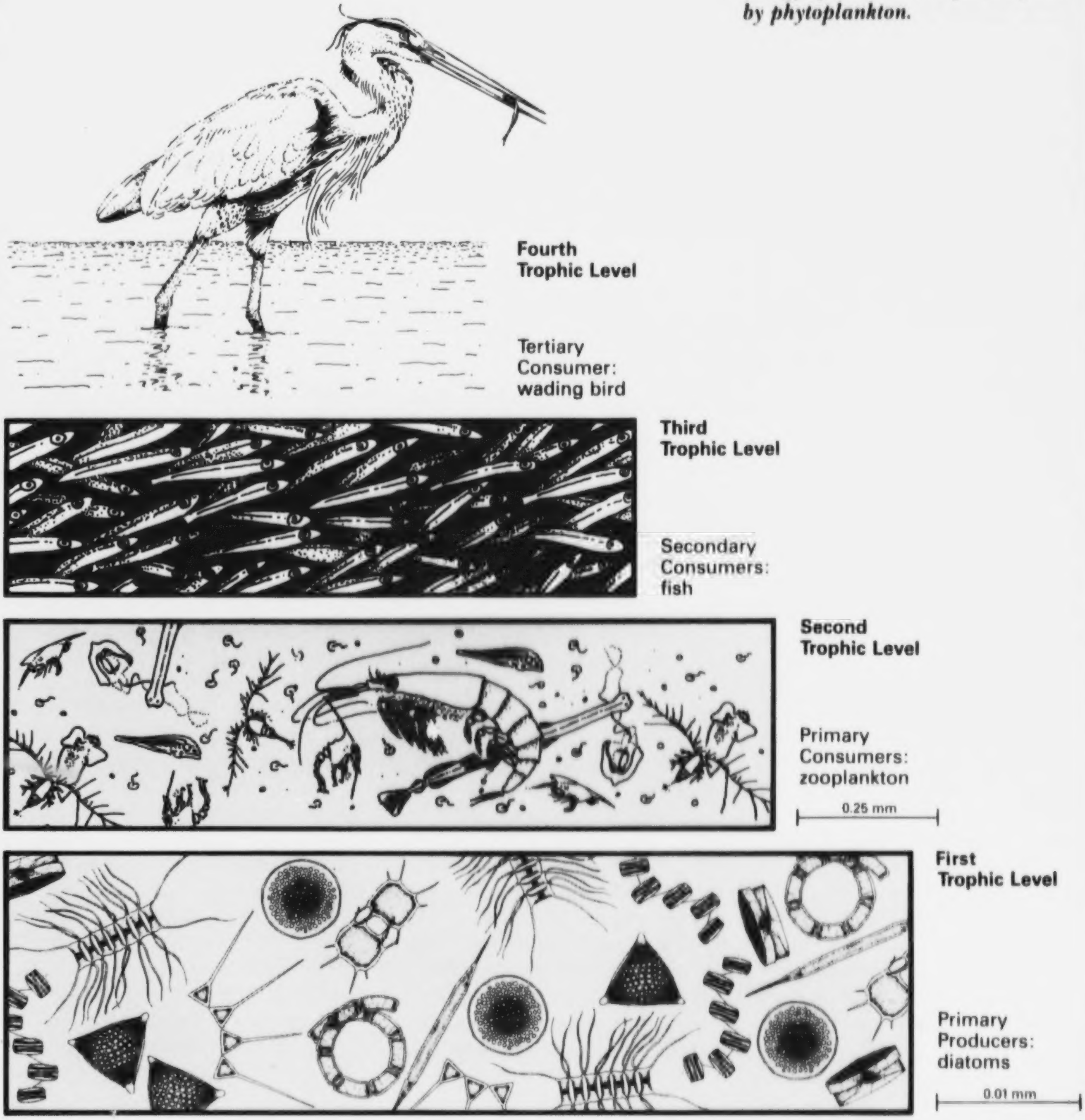


Figure 12: A typical marine food chain. In much of the oceans, the energy of the sun is captured first by phytoplankton.

Fourth Trophic Level
Tertiary Consumer: wading bird
Third Trophic Level
Secondary Consumers: fish
Second Trophic Level
Primary Consumers: zooplankton
0.25 mm
First Trophic Level
Primary Producers: diatoms
0.01 mm

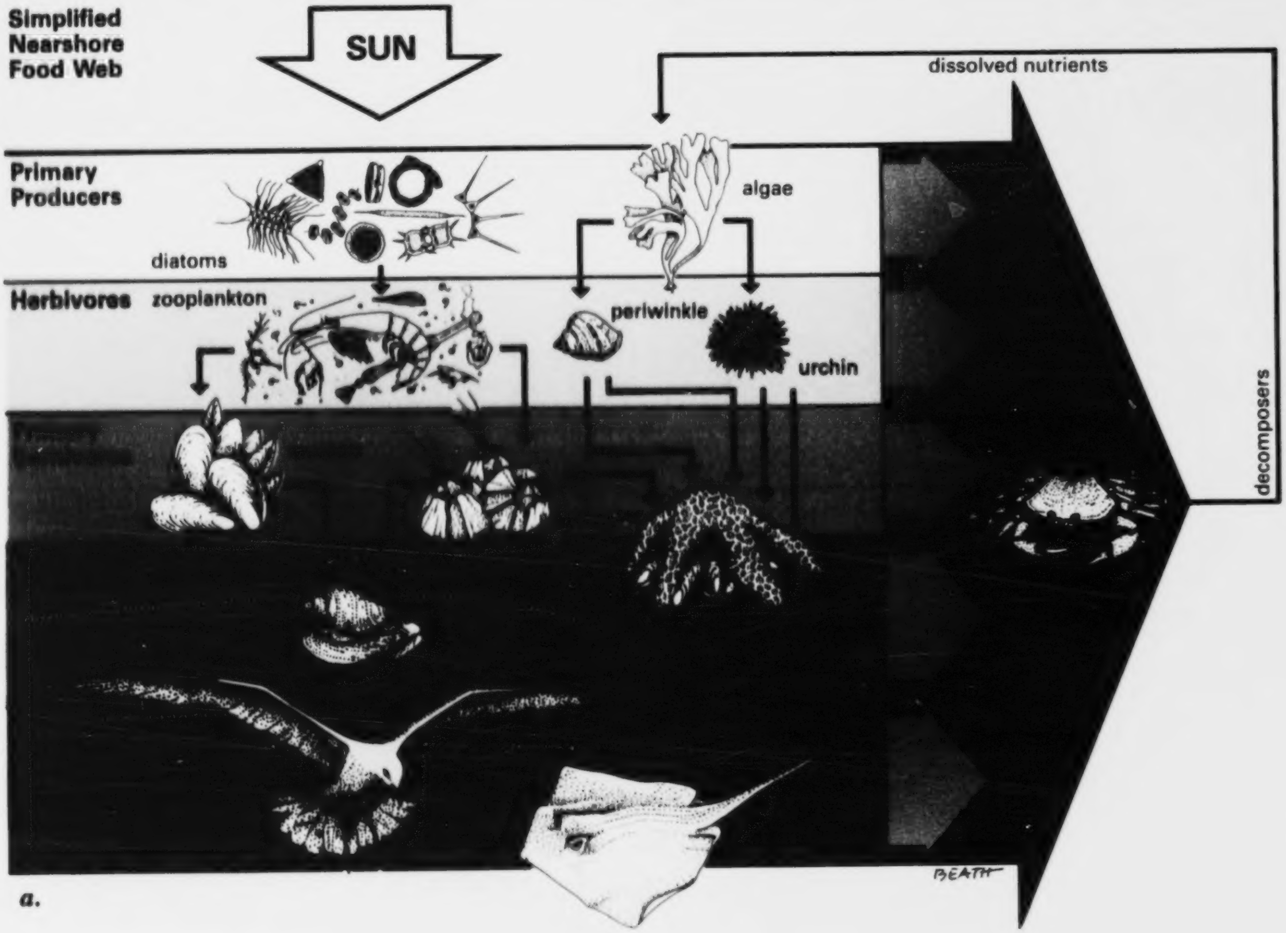
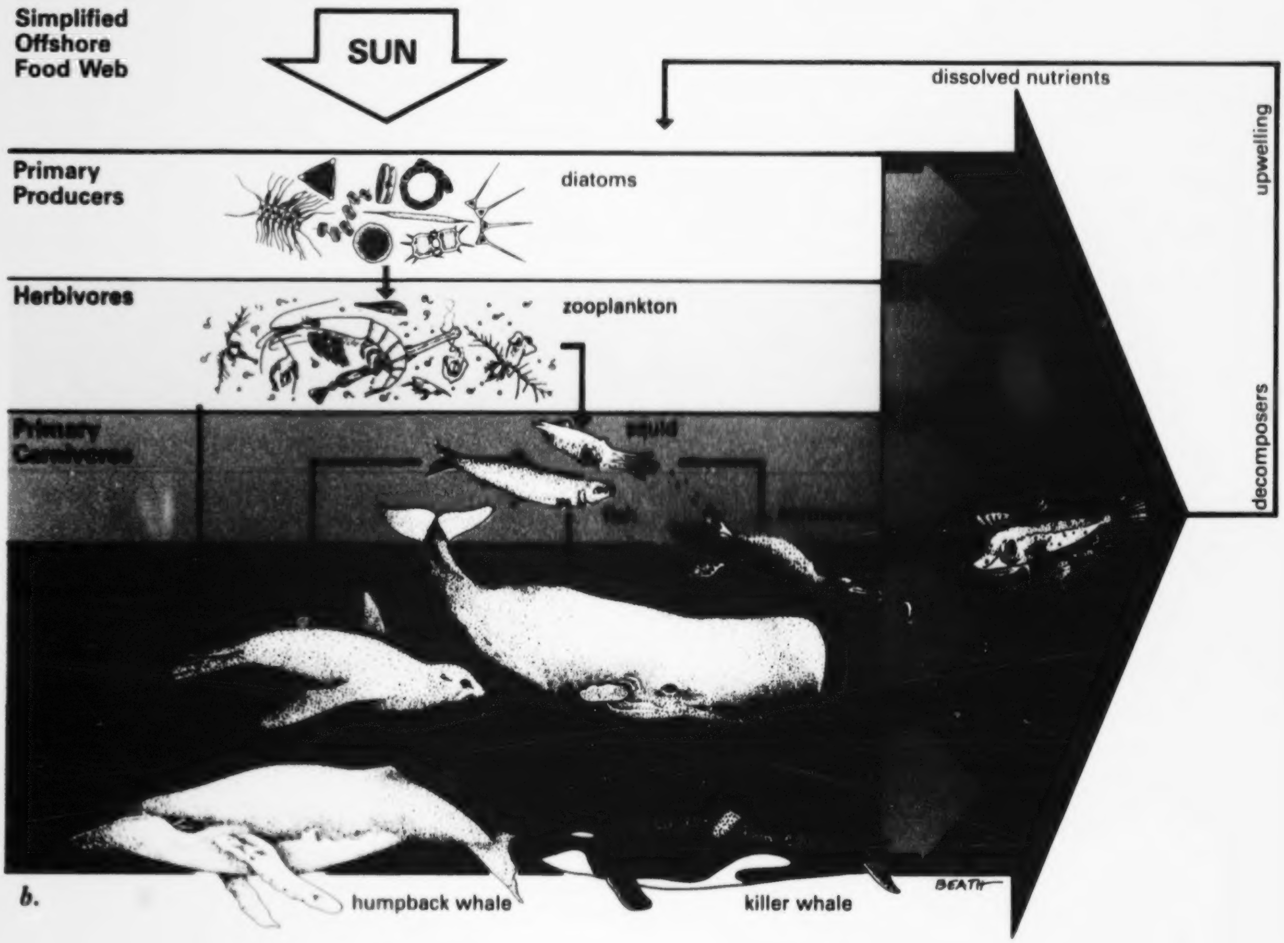


Figure 13: a) A simplified nearshore food web. b) A simplified offshore food web. A single species of animal may feed upon several species of plants and animals and, in turn, may be fed upon by several species of animals.

Generally each consumer species preys upon several other species. Likewise, an individual prey species is quite often preyed upon by several consumer species. These interrelationships are known as a food web and illustrate just one of the complex relationships among plants and animals in an ecosystem ***(Figures 13a and 13b)***.

The farther removed a species is from primary production, the higher its trophic level (troph= food). Only about ten percent of the energy at one trophic level can be captured by organisms of the next higher trophic level. Much of the energy captured by plants at the first trophic level is used by the plants themselves for respiration, the process by which



b.

plants and animals release the energy stored in carbohydrates. Only the energy left over after respiration can be passed on to zooplankton at the second trophic level. The zooplankton, then, uses much of the energy it obtains from the phytoplankton for respiration and passes on the remaining energy in the carbohydrates to fish at the third trophic level and so on up the hierarchy.

The way in which organisms obtain and use energy can reveal much about a marine ecosystem. Indeed, the cycling of energy among organisms is one of the first issues an ecologist must address in any ecosystem.

Submarine Canyons

The seaward edge of the continental shelf is scored in many places with deep submarine canyons ***(Figure 14)***. Some of these canyons begin less than one mile offshore in water as shallow as 100 feet and plummet to depths of 14,000 feet or more. The walls of these canyons often rise to more than 3,000 feet, and, in the case of the Great Bahama Canyon, more than 14,000 feet. The animals inhabiting these canyons are totally dependent upon a rain of plant and animal material from shallower waters where plant growth takes place.

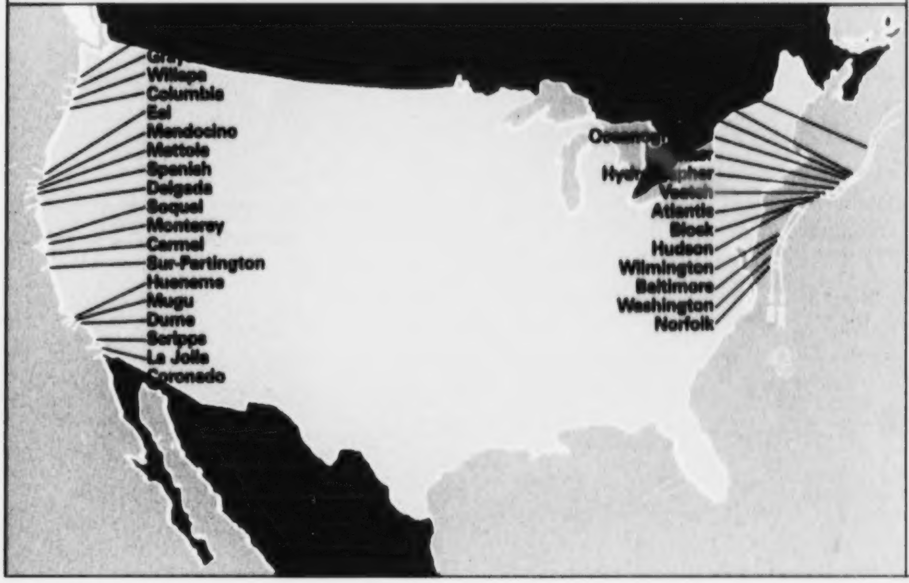


Figure 14: There are 18 major submarine canyons from the Gulf of Maine to Cape Hatteras, all of which begin far offshore. At least 17 canyons lie off the west coast. All of these, the deepest of which is the Monterey Canyon, begin close to shore. There are also extensive canyons off Alaska and canyons off Hawaii.

Generally, the heads of submarine canyons are located on the continental shelf. From there the canyons wind seaward until they terminate on the continental rise. Canyons may stretch more than 200 miles, as does the Bering Sea Canyon, or as little as three miles, as does the Dume Canyon off Southern California. The slope of the canyon floor is greater at the head than elsewhere in the canyon. Often, tributary canyons join a larger canyon near the head and are sometimes suspended several hundred feet above the floor of the main canyon. Submarine valleys, formed from sediment transported down the canyon bottom, may fan out for many miles from the mouth of the canyon.

Although the walls of submarine canyons are nearly vertical in places, usually they are at an angle of about 30 degrees. The walls of the canyons, which may be anywhere from a few feet to many miles apart, are often covered with sand, silt or gravel, although sometimes they are scoured clean by currents within the canyon. Water currents within canyons seem to be concentrated at the shallower and narrow heads where the combination of tides, storms, and internal waves may dislodge large accumulations of sediment.

Because plants cannot grow in these deep canyons, life in the canyons depends upon the plant life in the shallower waters above the canyons. Most of the food in submarine canyons, however, is waste from zooplankton and the carcasses of marine animals. As this food falls from surface waters, it is consumed by bacteria and detritus feeders. As a result, the amount of available food decreases with depth.

Some food material may spill into the canyons from the continental shelf. Canyons are sometimes richer in food sources than the surrounding continental slope and rise because canyons, like funnels, focus food spilling from the continental shelf. Also, animals which migrate vertically can contribute to the transfer of food from shallower to deeper waters. Predators in shallow waters may become prey in deeper waters.

Because of the remoteness of submarine canyons, much remains to be learned about the dynamics and distribution of animal populations in these areas. Studies off the east coast suggest that canyons have a greater abundance of epibenthic (epi=on) animals, such as anemones and soft corals, than do the continental slope and rise. This is because canyons offer more hard substrate to which these organisms can attach than do the continental slope or rise. These epifauna (fauna=animals) also depend upon currents to carry food to them. Among the most common forms of soft corals in the canyons are sea fans, which form extensive lattice-like colonies extending up from the bottom and, like sieves, filter particles of food out of the passing water. Where fine sediment covers the walls or floor of a canyon, other epibenthic species dominate.

A variety of animals move about the bottom feeding upon other animals or upon detritus. Among the most active of these animals are red and jonah crabs, which dig into the muddy parts of walls of submarine canyons in order to prey upon boring molluscs. In digging out their prey these crabs create burrows into which they or other small organisms retreat. As the inhabitants expand the size of the burrows, they are displaced by larger organisms such as tilefish. Sometimes a canyon wall may become pocked with so many burrows that it takes on the appearance of an Indian cliff dwelling or a pueblo community ***(Figure 15)***. Eventually these burrows undermine the surface of the canyon wall so much that it collapses and tumbles to the floor of the canyon. In some canyons this process, called bioerosion, is a major contributor to the shaping of the typography of the canyon.

Among the fishes inhabiting submarine canyons, the most common is the rattail, a fish related to the more familiar cod. Exceptionally large eyes, sense organs along the head, and a small barbel at the chin help rattails locate prey as they root about in the sediment. Black-bellied rosefish, hake, eel, and flounder also are found frequently in submarine canyons.

Because submarine canyons have only recently become the focus of increasing scientific study, much remains to be learned about how the canyons are shaped, their productivity, and the interactions of their inhabitants.

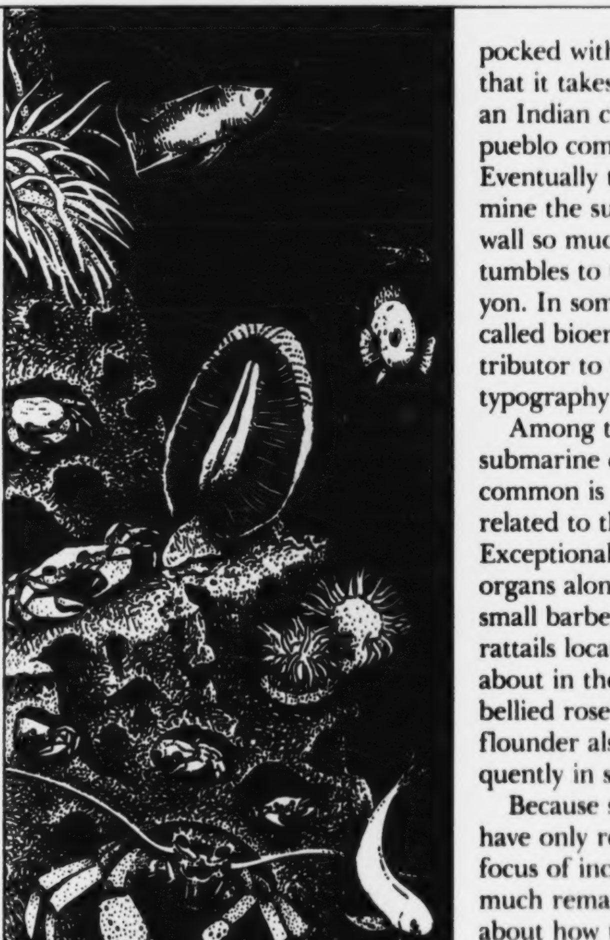


Figure 15: The walls of submarine canyons may become so pocked with the burrows of crabs and other animals that the walls collapse. Likewise, massive underwater waves and upwelling may alter the floor and walls of canyons.

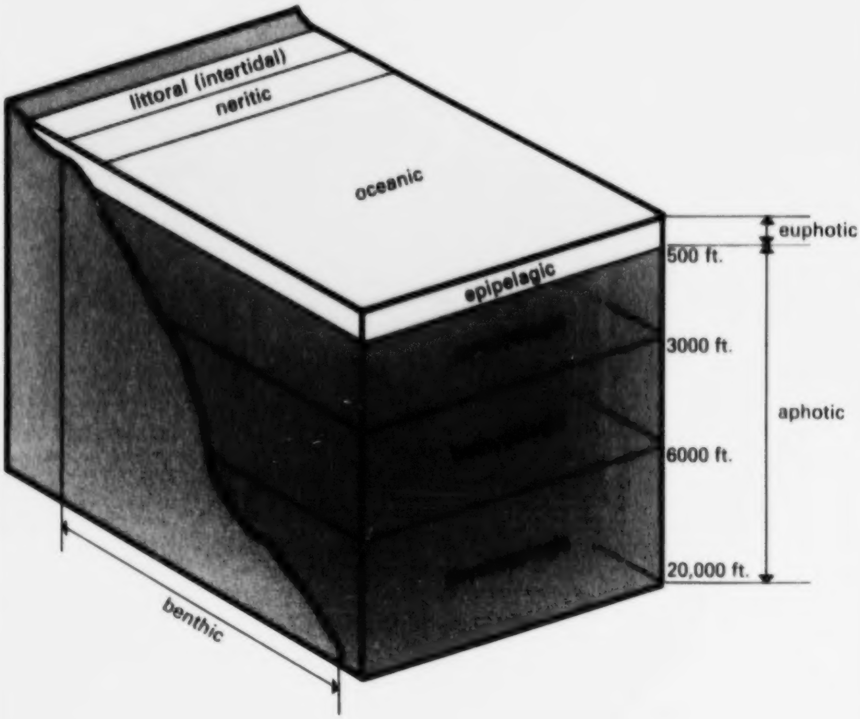
MARINE ECOLOGY

The Physical Environment of the Ocean

Scientists use vertical and horizontal divisions of the ocean in discussing various ocean environments ***(Figure 16)***. For instance, the uppermost zone of the ocean, into which light penetrates enough to allow plant growth, is called the euphotic zone (eu= good, phot= light). In turbid coastal waters this zone may be only 90 feet or less in depth; in clearer mid-oceanic waters, the euphotic zone may extend down to 600 feet. The amount of light penetrating the water gradually diminishes with depth until none at all is able to get through. This marks the beginning of the aphotic zone (a= without). The aphotic zone makes up over 95 percent of the oceans.

Depth also increases the pressure exerted by water on organisms. The air pressure at sea level is 14.7 pounds per square inch or one atmosphere. This is the weight of a column of air, one inch square, reaching from the

Figure 16: The principle vertical and horizontal divisions of the oceans. Ocean currents can dramatically change physical conditions in any zone.



ground to a height of about 100,000 feet. Because sea water is about 800 times heavier than air, the pressure per square inch increases one atmosphere for each 33 feet of additional depth in sea water. Thus, the water pressure at 6,000 feet is nearly 300 times greater than the pressure we feel when snorkeling at the surface. Despite these great pressures, ocean depths are by no means without life. The adaptations of animals in these zones to the total lack of light and to the tremendous water pressures are among the most remarkable in the animal kingdom.

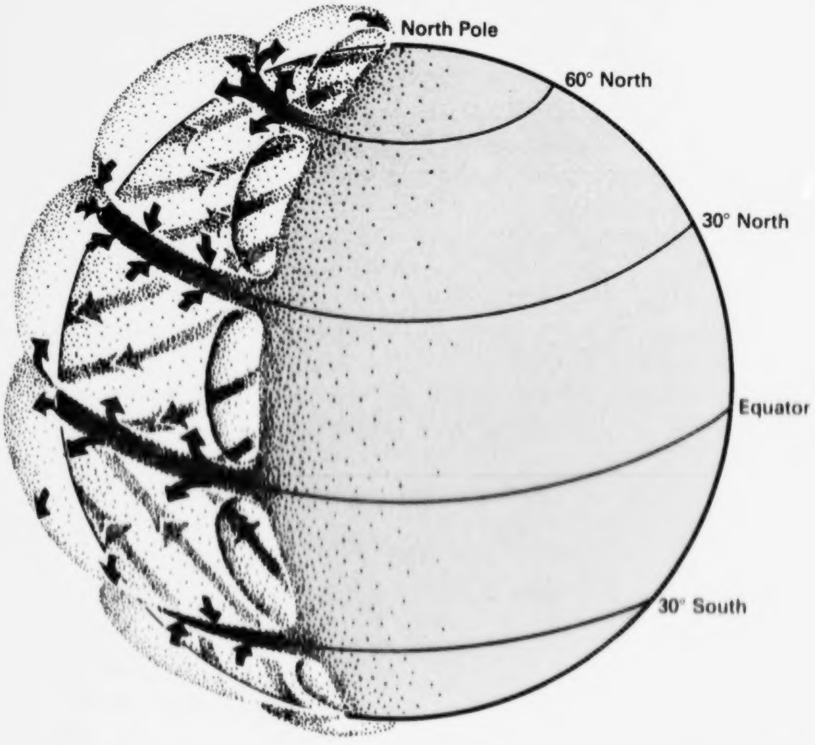


Figure 17: The heat of the sun and the rotation of the earth cause the air to circulate in large patterns called Hadley cells. These cells generate prevailing winds.

The sun affects ocean environments in other ways. Because of the curvature of the Earth and the atmosphere, polar regions receive less sunlight than do equatorial regions. Both the air and the surface water of tropical regions are, therefore, warmer than those of polar or temperate regions. To maintain the broad atmospheric heat balance of the earth, the warm air of the tropics tends to move toward the colder polar regions ***(Figure 17)***. As it rises and moves toward the poles, this warm tropical air cools and becomes denser, creating a high pressure area in polar regions. On the other hand, the cooler and heavier polar air moves toward the low pressure in the tropics, creating a relatively steady wind from the north in the northern hemisphere and from the south in the southern hemisphere.

The movement of these air masses is complicated by the rotation of the earth. Due to an effect of the earth's rotation that deflects all moving bodies to the right (known as the Coriolis force), a warm tropical air mass in the northern hemisphere that is moving toward the north pole is deflected to the right and eventually forms a gyre turning clockwise. Some of the cooled tropical air flows beyond the gyre, and becomes part of a second, temperate gyre.

The movement of these air masses creates winds, which in turn drive ocean currents. The easterly winds that blow near the equator, for instance, drive the great equatorial currents of the ocean. As these currents move westward, they are deflected to the right by the Coriolis force and by the continents ***(Figure 18)***. These major currents and the many countercurrents and eddies

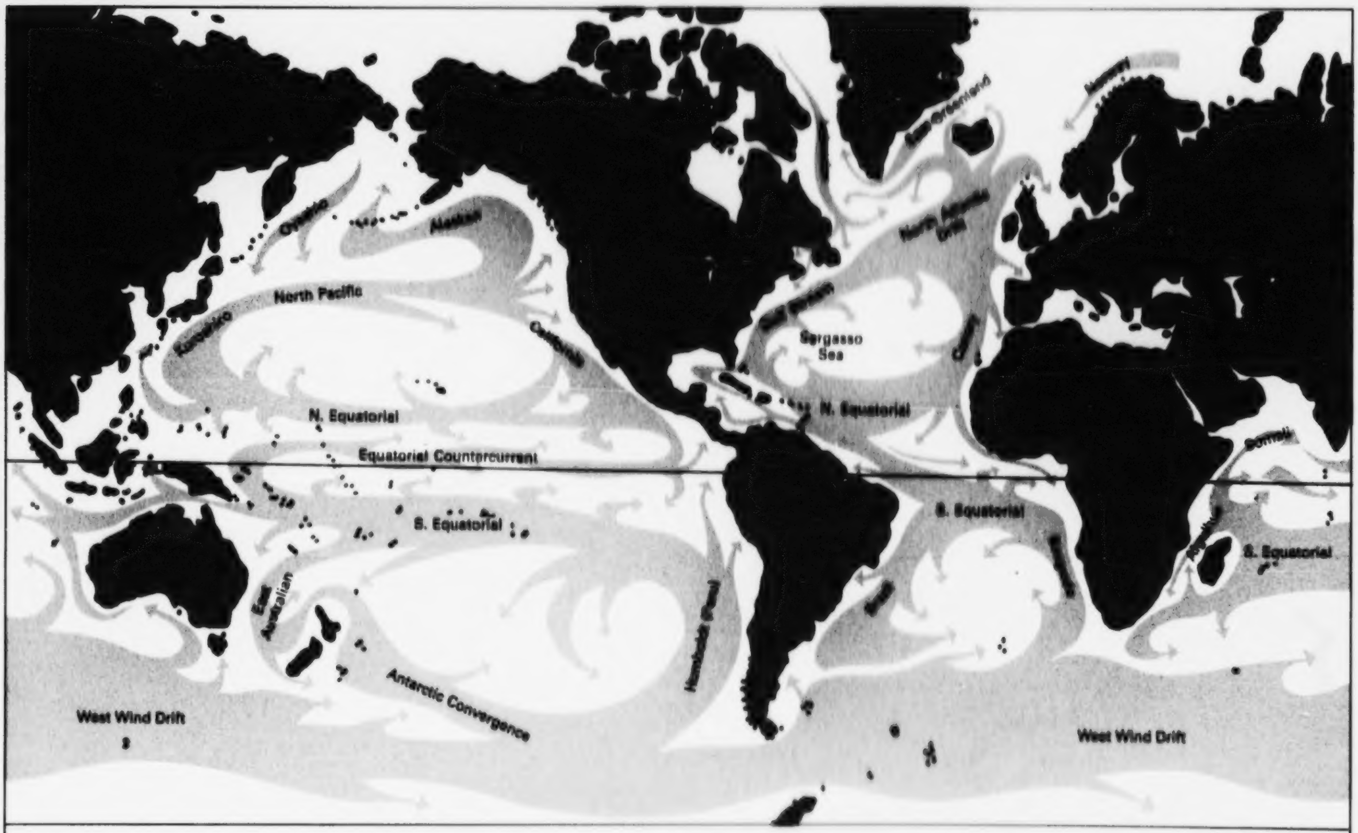


Figure 18: The major ocean currents are driven by prevailing winds, the rotation of the earth, and the heat of the sun. Differences in the chemistry of adjacent layers of water can generate currents as well, when heavier water sinks below lighter.

circulate the water in the oceans, the mineral elements in the water, and much of the plant life upon which other life in the oceans depends.

Because water retains heat much better than does the atmosphere, the temperature of the oceans does not change abruptly. However, the temperature of the oceans is not uniform. Not only is surface water in the polar regions much colder than that in temperate or tropical regions, but the temperature of the oceans also changes with depth.

Colder water is denser than warmer water. Similarly, more saline water is denser than less saline water. As a result, the ocean is layered with water masses of different salinity and temperature. These water masses can move in different directions and at different speeds. But more important, the boundaries between such layers can form effective barriers to migration between the layers by marine organisms. Some organisms cannot tolerate the temperature or salinity differences that would be encountered in moving from one water mass to another.

All of these variables create a broad variety of environments for life in the oceans, which explains to some extent the diverse forms that life has taken on in the oceans.

Hydrothermal Vents

Only very recently did scientists discover a series of self-contained ecosystems deep in the lightless zones of the ocean off the west coast of the United States ***(Figure 19)***. The food web in these ecosystems is based not on plants but on certain bacteria that use the energy found in hydrogen sulfide, a chemical poisonous to most animals. No photosynthetic plants are found in these sea bottom-based systems, and none of the animals living there need to scavenge on the remains of plants or animals drifting down from the surface.

The hydrogen sulfide is dissolved in the hot water which flows from springs at fissures and vents in the sea floor. Bacteria get energy from the hydrogen sulfide by oxidizing it. They then use this energy to convert the carbon in carbon dioxide dissolved in the sea water into organic carbon. Because the water from the hydrothermal (hydro=water, therm=heat) vents is so rich in hydrogen sulfide, the bacteria are able to form dense masses in and around the hot water vents. Despite their microscopic size, they are the primary producers in the food web of the vent ecosystem, a role normally played by plants. Through the food chain, they support a wide variety of other organisms.

Organisms around the hot springs sometimes take bizarre forms. Among the animals found at the springs are huge clams of a species formerly unknown to science, measuring up to a foot or more in length and having pink flesh. The pink is due to the fact that their blood contains oxygen-carrying hemoglobin, a substance not found in most clams and apparently an adaptation to the low oxygen levels of the environment. The clams have a growth rate of about one and a half inches a year, 500 times faster than that of other deep-sea clam species.

Also found at the springs are two species of blind snow-white crabs. The more abundant of these crab species resembles a crawfish and is related to hermit crabs. The other species, which feeds on bacteria, worms, and

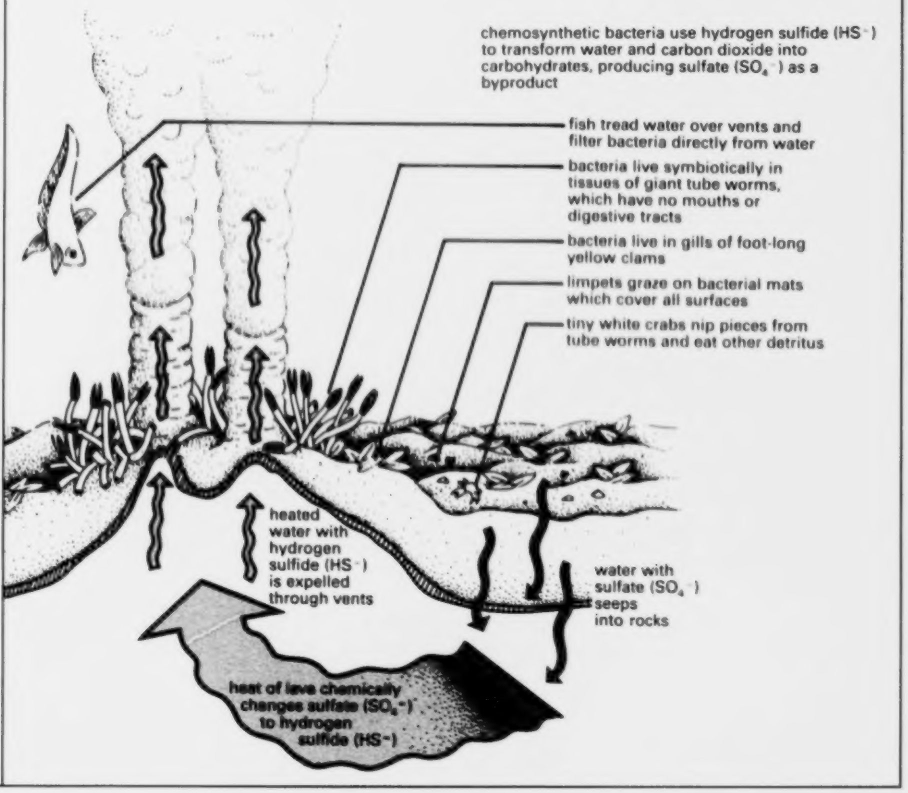

chemosynthetic bacteria use hydrogen sulfide (HS^-) to transform water and carbon dioxide into carbohydrates, producing sulfate (SO_4^-) as a byproduct
fish tread water over vents and filter bacteria directly from water
bacteria live symbiotically in tissues of giant tube worms, which have no mouths or digestive tracts
bacteria live in gills of foot-long yellow clams
limpets graze on bacterial mats which cover all surfaces
tiny white crabs nip pieces from tube worms and eat other detritus
heated water with hydrogen sulfide (HS^-) is expelled through vents
water with sulfate (SO_4^-) seeps into rocks
heat of lava chemically changes sulfate (SO_4^-) to hydrogen sulfide (HS^-)

Figure 19: Through chemosynthesis bacteria function as primary producers in the total darkness of deep water hydrothermal vent ecosystems. These areas are like oases on the ocean bottom.

other small organisms, is distantly related to the blue crabs of the Atlantic Ocean and represents a new superfamily of crabs.

The most visually striking members of the ecosystem of the hydrothermal vents are giant red worms stretching up to eight feet in length and living in white parchment-like tubes. These worms, of a new family, have no mouth or digestive organs. The exact method they use to get nourishment is unknown, but they are believed to absorb nutrients directly from the water through their outer surfaces. The tubes that the worms build are often spotted with the dark shells of limpets, themselves representatives of seven new families.

The vents host a number of other unusual life forms. Large mussels of a new genus live with internal structures distinctly different from those of all other known mussels. Worms of another kind, this time white in color, drape themselves over the rocks at the vents in such a way that scientists dubbed them "spaghetti worms." Thought at first to be a new family, they were found later to be members of a group of worms normally making their homes buried in the sediments of soft bottom areas. Another unusual creature was named "dandelion" because its yellow color and round shape resemble the common lawn weed. It is actually a colonial jellyfish related to the Portugese man-o'-war.

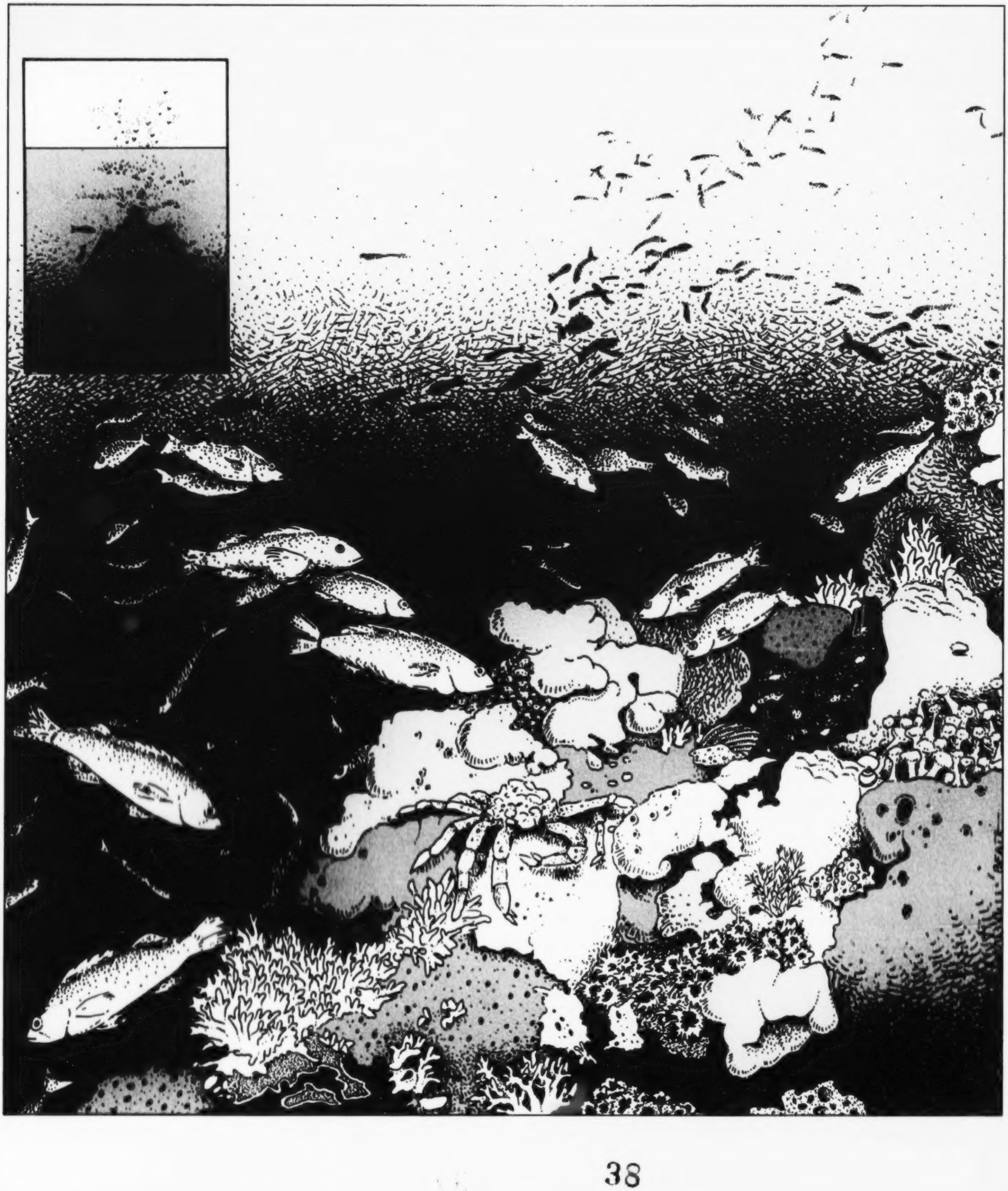
Because their food supply is 300 to 500 times more concentrated than that of the surrounding waters, vent communities are rich in life. But when a vent stops flowing, the supply of hydrogen sulfide is cut off and the life of the vent ends. For example, at one extinct vent called "the clambake," the bottom is littered with the shells of dead clams and mussels, the remains of a once thriving community that died when the supporting vent ceased giving forth the water that carried the essential hydrogen sulfide.

Seamounts

In many areas of the oceans the sea floor rises in peaks toward the surface ***(Figure 20)***. When the tops of the peaks are above the water they are called islands. Where they only approach the surface but do not break it, they are called seamounts. Seamounts exist in parts of the oceans and usually have little ecological effect. Sometimes, however, the seamounts rise high enough to reach into the euphotic zone. When this occurs, they support rich ecosystems unlike those of the deeper surrounding areas.

Commercial and recreational fishermen have long recognized the importance of seamounts. Seamount ecosystems often support important fisheries as fish gather at the seamounts for the food and shelter to be found there. For the same reasons as the fishermen, marine mammals and seabirds often congregate over seamounts.

Figure 20: Where the seafloor is lifted into the euphotic zone, abundant sealife may be found far from land. These seamounts attract seabirds and marine mammals in great numbers.



Cordell Bank, about 50 miles northwest of San Francisco, California, is an excellent example of a seamount ***(Figure 21)***. It is large, about ten miles long and five miles wide. The top of the seamount is relatively flat with depths ranging from 180 to 210 feet. A number of steep jagged ridges rise abruptly from the main surface of the seamount to depths of 120 feet. The water there is clear and cold with a high nutrient content. Because of this, the local community of plants and animals is exceptionally vigorous, and the number of attached organisms is limited only by the availability of space.

Scuba divers are exploring the areas of Cordell Bank, generally less than 150 feet deep, which they can safely visit. They describe the bottom as enormous piles of plants, sponges, anemones, and corals, in bright reds, pinks, yellows, and white. Above them are huge swarms of juvenile rockfish, sometimes so numerous that they obscure the vision of the divers. Cameras lowered to slightly greater depths, around 200 feet, show the rock to be bare.

At the surface of the water above the peaks of the banks swarm large numbers of birds and marine mammals, all apparently feeding. So noticeable are the birds that boaters actually navigate by them, knowing that when they are among the birds they are over the bank. Bird watchers make frequent trips to these sites and have identified pelicans, loons, albatross, terns, murres, gulls, and others. Northern fur seals, California and Steller sea lions, Dall's porpoises, and blue, gray, and humpback whales also are found at Cordell Bank.

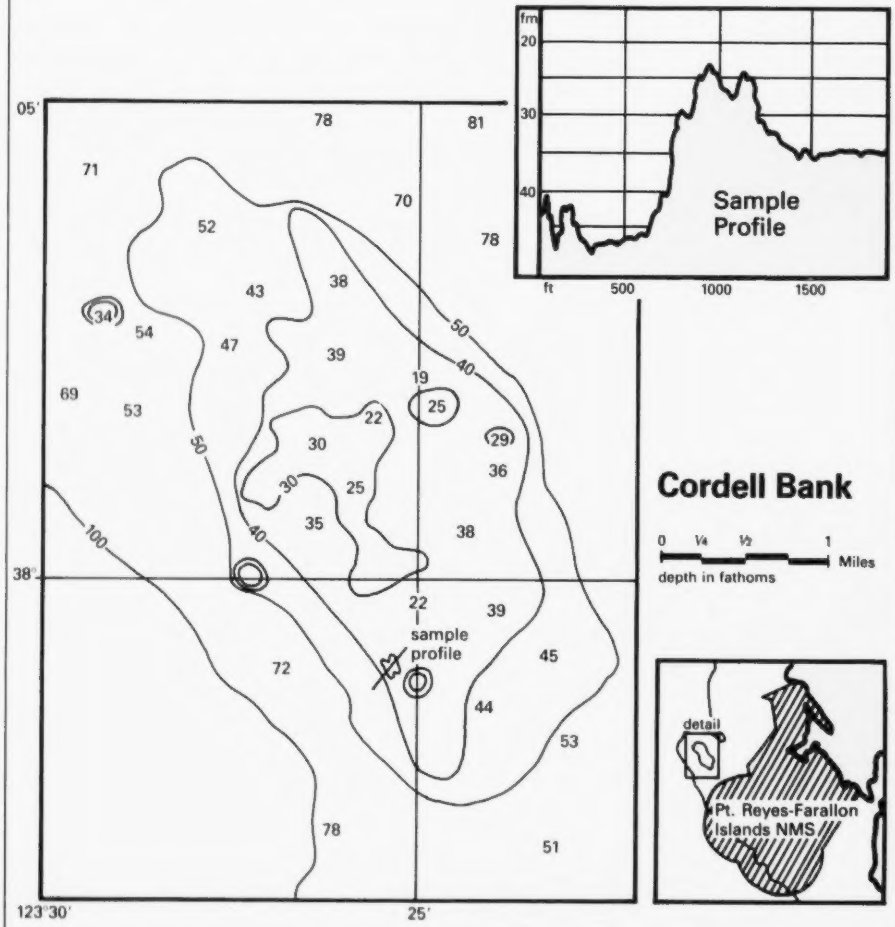
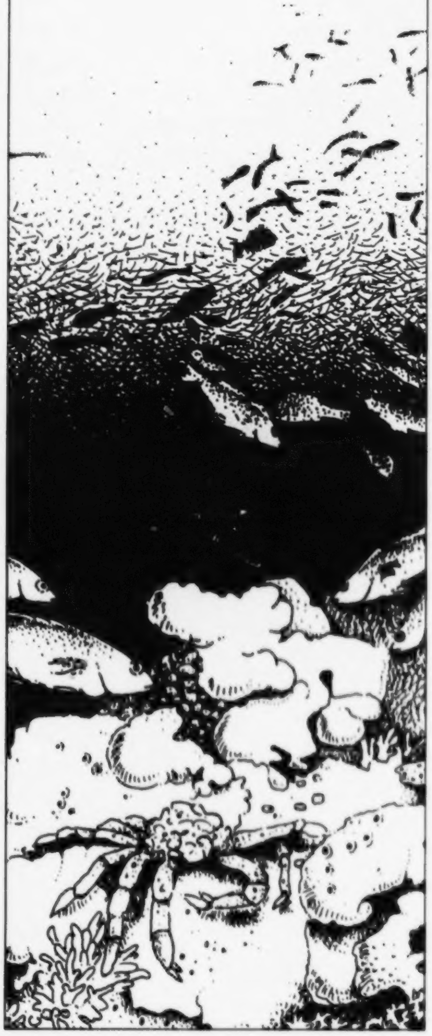


Figure 21: Cordell Bank, a seamount located just outside the Point Reyes-Farallon Islands National Marine Sanctuary, is itself being considered for sanctuary designation. In the upper right corner is a profile of the seamount based on a transect taken in the area shown on the map below.

CASE STUDY

Cordell Bank



We often think that human knowledge has penetrated every area of the Earth, and that there are no frontiers left to challenge explorers and scientists. Cordell Bank provides an illustration of just how wrong this idea is. The bank was discovered in 1853 by a party from the U.S. Coast Survey. A single cast of a lead line was all that was done at the bank on that occasion. Fourteen years later the bank was rediscovered and its general contours were mapped. Various research groups later made efforts to refine the early findings and the bank was thought to have been relatively well charted by the 1920's.

A series of diving expeditions in the late 1970's and early 1980's showed that the early surveys were very much in error. Because they made only a few soundings the early mappers of the bank were unable to show bottom features having dimensions smaller than about a quarter of a mile. It has been since discovered that many of the significant features of the bank are much smaller than that. For example, one ridge on the bank is shown on the best charts as coming no closer to the surface than 150 feet. In truth a part of the ridge rises within 114 feet of the surface. The scientists who have been studying the bank believe that many similar discrepancies remain to be discovered.

Within several miles of the bank, which lies on a plateau 300–400 feet deep, the bottom drops off to depths greater than 6,000 feet. The southward flowing California Current is deflected by the bank, causing the upwelling of nutrient-rich ocean waters. As a result, Cordell Bank is a kind of oasis on the continental shelf, supporting many species from rare hydrocorals to humpback whales.

Divers have found several uncommon and rare species of plants and animals at the bank as well as at least two new genera and one new species of algae, a new species of marine snail, and several other organisms which may be previously unknown. They expect that further dives will reveal many other species previously not described by science. Cordell Bank proves that the ocean is still a largely unknown frontier.

Hard Bottoms

In the Atlantic, off the southeastern coast of the United States, the broad, sandy, mostly barren continental shelf is irregularly broken by banks of rocky outcroppings covered with plants and animals *(Figures 22 and 23).*

Figure 22: In places, shallow, rocky outcroppings break the otherwise flat, muddy bottom of the Atlantic off the southeastern United States. These banks host a wide variety of animals from sponges and corals to large groupers and loggerhead sea turtles.

Offshore Georgia and South and North Carolina, such hardground banks occur on the inner, middle, and outer continental shelf at depths of 50-80 feet, 100-130 feet, and 200-330 feet respectively. Some of these banks may rise only a few feet above the bottom and may be easily covered by shifting sand. Others may have a total vertical relief of 20 feet or more, and include overhanging ledges, caves, burrows, and sandy rock-littered troughs.

These rocky outcroppings, which are often called hard bottoms, provide firm surfaces to which plants and animals can attach themselves. Different communities have developed on the various hard bottoms scattered off the southeastern U.S. Outer and middle shelf hard bottoms, for example, are regularly exposed to the warmer waters of the Gulf Stream. Thus, warmwater species of fish and coral, classified as stenothermal (steno=narrow, therm=heat) because they are able to live only within a very narrow range of temperatures, inhabit these outer and middle shelf hard bottoms. Inner shelf hard bottoms, on the other hand, which are exposed to colder inshore waters and runoff of freshwater from the land, experience wider fluctuations in water

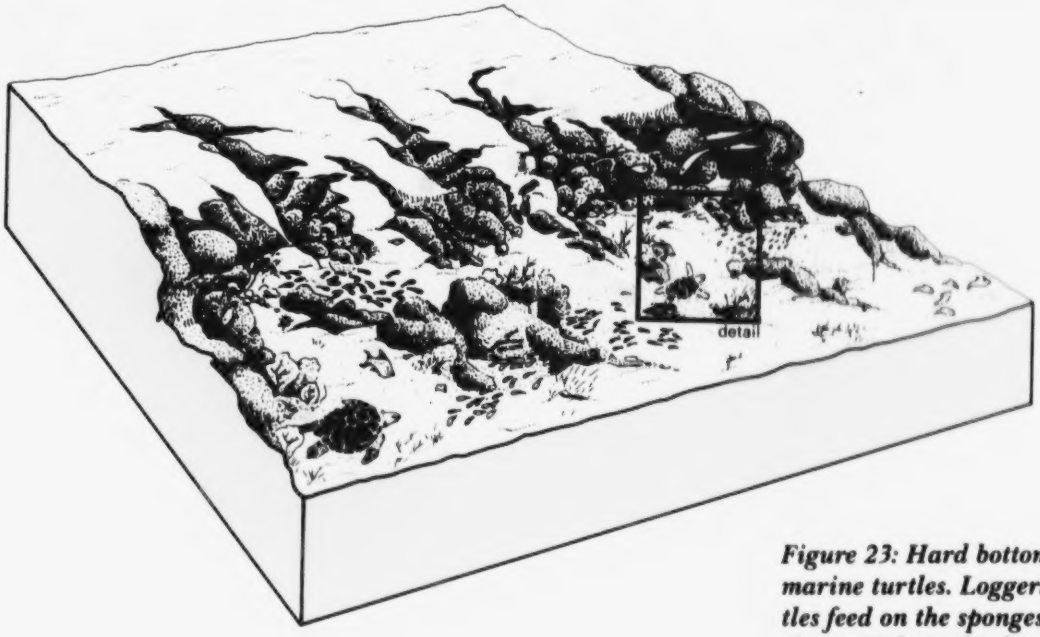
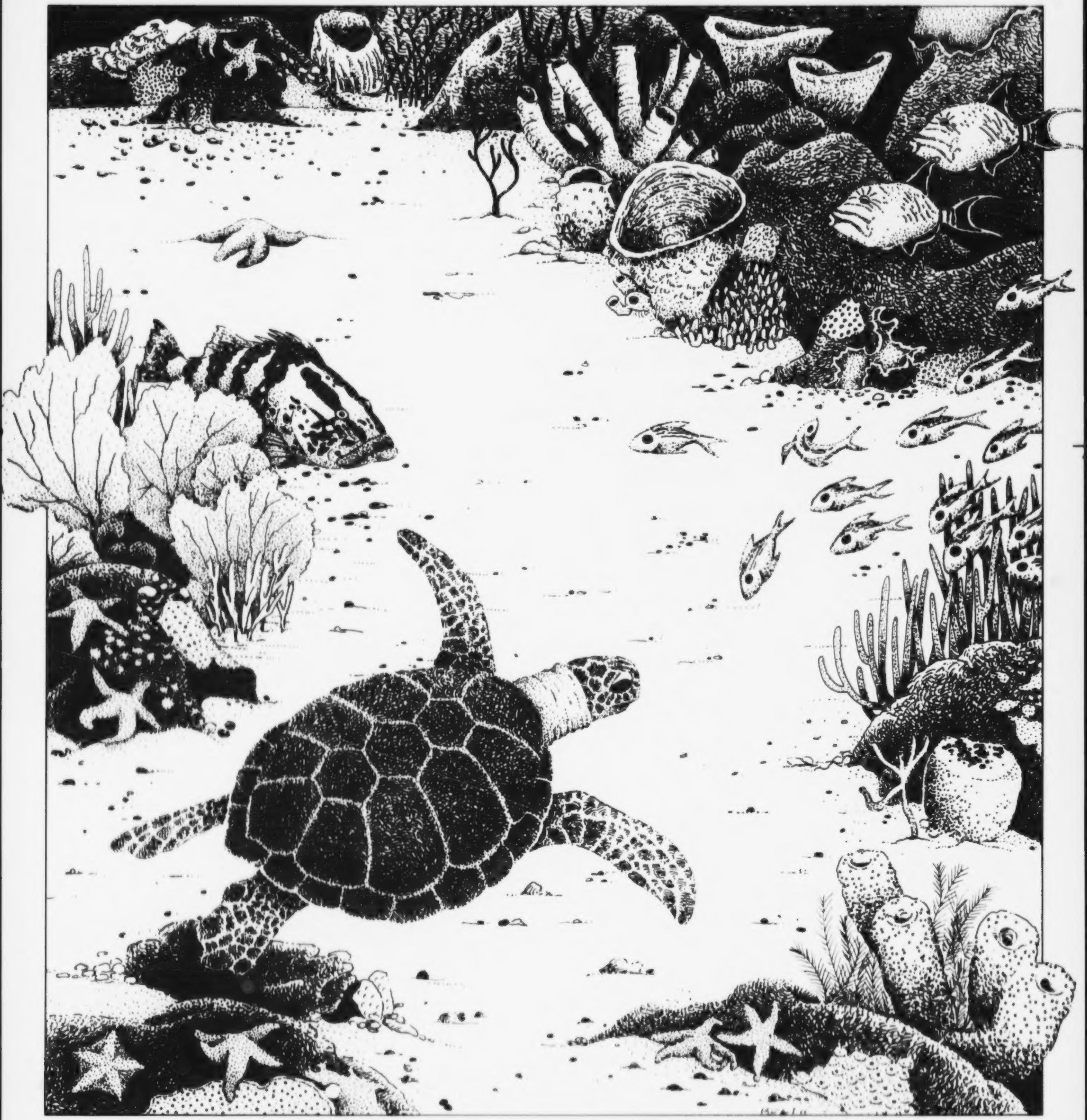


Figure 23: Hard bottoms attract marine turtles. Loggerhead sea turtles feed on the sponges, crabs, clams, and conchs there. Sea turtles also use the overhangs of hard bottoms for shelter.



temperature and salinity. Species on these hard bottoms are generally eurythermal (eury=broad) and euryhaline (hal=salt). At times when the nearshore waters are warm enough, warmwater stenothermal species may be found on these inner shelf live bottoms.

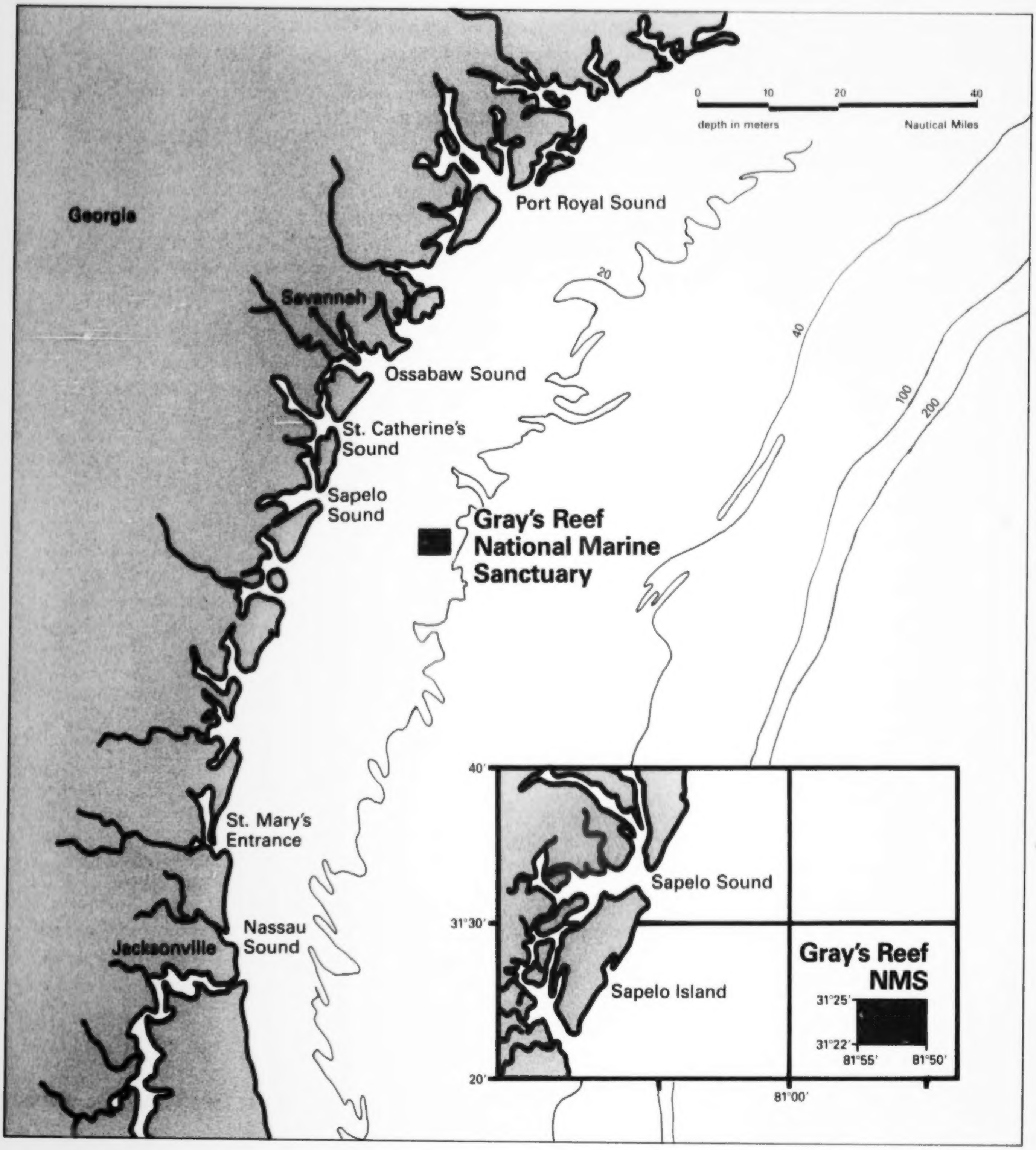
Among the species attaching themselves to hard bottom areas such as at the Gray's Reef National Marine Sanctuary off Sapelo Island, Georgia, are hard corals—star coral, cup coral, and branching eye coral ***(Figure 24)***. These species in the Gray's Reef sanctuary are near the northern limit of their geographical range. Soft corals found at Gray's reef include sea fans and sea whips whose thousands of individual coral polyps may take on the form of delicate feathers or whips. Barnacles, sponges, tunicates or sea-squirts, hydroids, and tube-building worms also live on the substrate of the hard bottom. All of these sedentary, filter-feeding animals depend upon water currents around the hard bottom for circulation of food and for removal of wastes.

Other invertebrate (in=without, vertebra=backbone) animals wander about hard bottoms and use overhangs, caves and burrows for shelter. These include various species of marine snails such as deer cowrie, common slipper snail, and Florida horse conch. There are also the bivalve molluscs, American cockles and rigid pen shells. Octopus may be found skirting across the sandy bottom surrounding a hard bottom or hiding beneath overhangs. Starfishes, brittlestars, sea urchins, crabs, and lobsters also live at hard bottoms.

Hard bottoms are often associated with rich commercial and recreational fisheries. Some finfishes are permanent residents of hard bottom areas while others make use of the bottoms only seasonally. How finfish use the hard bottoms varies with the size of fish and their age. The smaller species remain within the general boundaries of a hard bottom area. Larger species may school above hard bottom areas during the day, but forage over a broader area during the night. Furthermore, the habitat preferences of these larger species may change over time. Thus, juvenile snappers are generally found in shallow hard bottom areas, while the older and larger snappers are found farther offshore.

Many questions about hard bottom ecosystems await answers. Only recently has much research been conducted regarding the structure and dynamics of such ecosystems. Also, little is known about the exact distribution of these marine oases in U.S. waters.

Figure 24: Designated in 1981, the Gray's Reef National Marine Sanctuary lies east of Sapelo Island, Georgia. The live bottom area is one of the more extensive off the southeastern coast of the United States.


Georgia
Port Royal Sound
0
10
20
40
depth in meters
Nautical Miles
20
40
100
200
Savannah
Ossabaw Sound
St. Catherine's Sound
Sapelo Sound
Gray's Reef National Marine Sanctuary
St. Mary's Entrance
Nassau Sound
Jacksonville
40′
31°30′
20′
81°00′
Sapelo Sound
Sapelo Island
Gray's Reef NMS
31°25′
31°22′
81°55′
81°50′

CASE STUDY

Gray's Reef

In recent years commercial fisherman have attempted to catch snapper, grouper, porgy, and black sea bass using roller-rigged trawls rather than the more traditional hook and line. A roller-rigged trawl is a large funnel-shaped net which is towed along the bottom behind a boat. Rollers along the bottom of the net allow the trawl to be pulled up and over low rocky outcroppings, thus avoiding snagging and tearing. Researchers have also been using the same kind of trawls to capture fish and invertebrates in surveys of living marine resources.

Scientists working under a grant from the National Marine Sanctuary Program sought to determine the overall effects of the trawling by examining its effects on several species of animals. For this study, scientists selected a hard bottom area outside the Gray's Reef sanctuary and assessed the distribution and density of the different sponge and coral species living in that area. Next, the scientists towed a roller-rigged trawl over the area, and counted the number and types of sponges and corals caught up in the net. Divers then surveyed the trawled areas and counted the number of damaged sponges and corals. They resurveyed these areas again twelve months later in order to determine whether the sponge and coral populations had recovered.

Although the density of barrel sponges, particularly, was considerably reduced by the trawling, the sponge and coral populations had reestablished themselves within the twelve months. The scientists pointed out, however, that had the area been trawled more than once, the damage might have been more extensive and recovery within a year less likely.

Besides studying the effects of trawling, the scientists also studied the tiny animals that use sponges or coral for shelter or food. Polychaete worms and small crab-like creatures called amphipods were the most frequently found animals living in the many holes and crevices of sponges. These animals are said to have a commensal (com=together, mensa=table) relationship with the sponges, since they obtain their food from the water that the sponge draws into, then expels from its own body. These commensals are themselves part of the diet of several commercially important species of fish.

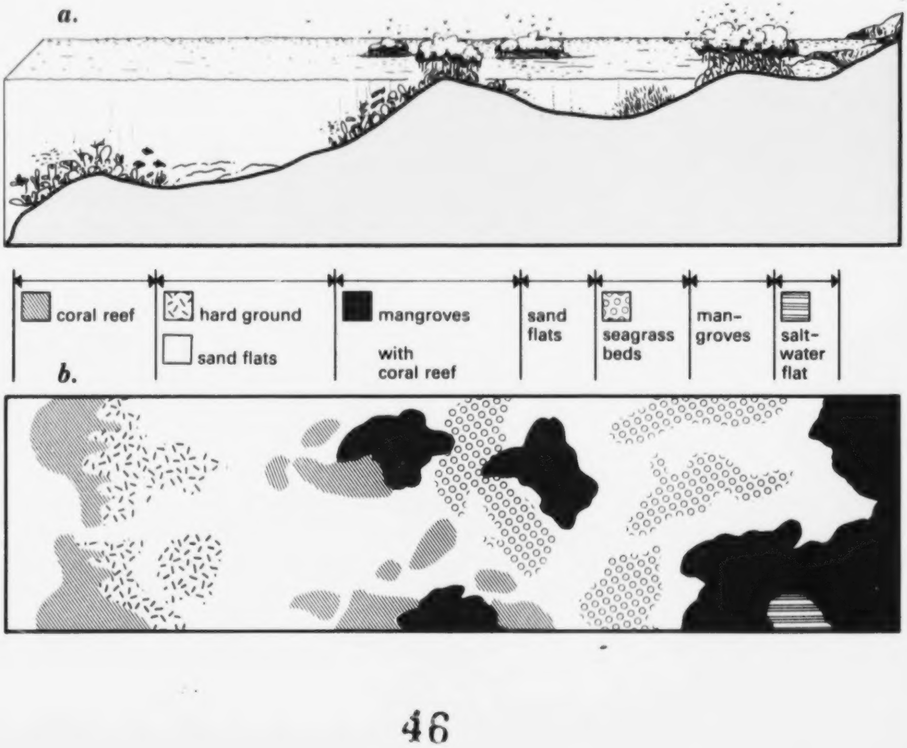
This study indicates quite clearly that the use of roller-rigged trawls for commercial fishing or scientific purposes can damage species of animals that attach themselves to hard bottoms. The study also confirms the wisdom of the prohibitions on the use of trawls within the Gray's Reef Sanctuary.

NEARSHORE TROPICAL ECOSYSTEMS

The ease with which marine plants and animals in coral reef, mangrove, and seagrass bed ecosystems can be observed by the scientist, the vacationing layperson, or the filmmaker has exposed millions of people to the fantastic array of life found in some tropical marine areas.

Although coral reefs are considered among the most efficient of all ecosystems, terrestrial or marine, they depend to some extent upon adjacent ecosystems as sources of primary production ***(Figure 25)***. Seagrass beds not only support their own community of organisms, for example, but also provide food for creatures, such as parrotfish, which spend much of their time on coral reefs. Likewise, both coral reefs and tropical seagrass beds in many areas depend upon the production of food by nearby mangrove forests. Furthermore, many organisms which spend their adult lives in seagrass beds or coral reefs also utilize the protection afforded by mangrove roots and seagrass blades at early stages of their lives.

Figure 25: a) A generalized cross section of a tropical shoreline area. b) Generalized distribution of mangrove, seagrass beds, and coral reefs in a tropical shoreline area. Tides, currents, waves, winds, and animals circulate food and nutrients among the various communities.



In the United States, associations of coral reef, seagrass bed, and mangrove ecosystems are found in Florida, the U.S. Virgin Islands, Puerto Rico, Guam, American Samoa, Saipan, Hawaii, and the U.S. Pacific Trust Territories. While neither the Key Largo nor the Looe Key National Marine Sanctuary off Florida encompasses mangrove areas, each does encompass extensive coral reef and seagrass bed ecosystems, and mangroves line the shoreline adjacent to both sanctuaries.

Mangrove Forests

The line between land and ocean is blurred considerably in mangrove forests ***(Figure 26)***. Here terrestrial plants have invaded the salt water environment very successfully and created a productive environment that supports a broad array of animals. Like estuarine and wetland ecosystems, mangroves provide a rich source of food for commercially important fish and shellfish.

Several abiotic factors affect the distribution of mangrove forests. Mangroves are, first of all, tropical species which grow best where annual average temperatures are above 66 degrees Fahrenheit. Second, mangroves do not develop well in freshwater where they cannot compete successfully with other plants. Third, the fluctuation of the tides alternately wets and dries the soil in which mangroves grow. And finally, mangroves grow best where there is little wave energy. Mangroves can grow on sand, rock, and peat, but flourish in fine-grained, anaerobic (an=without, aer=air) soil composed of silt, clay, and organic matter ***(Figure 27)***.

Bacteria, fungi, and other microorganisms cover fallen mangrove leaves, serving as a rich source of protein for shrimp, crabs, clams, and some species of

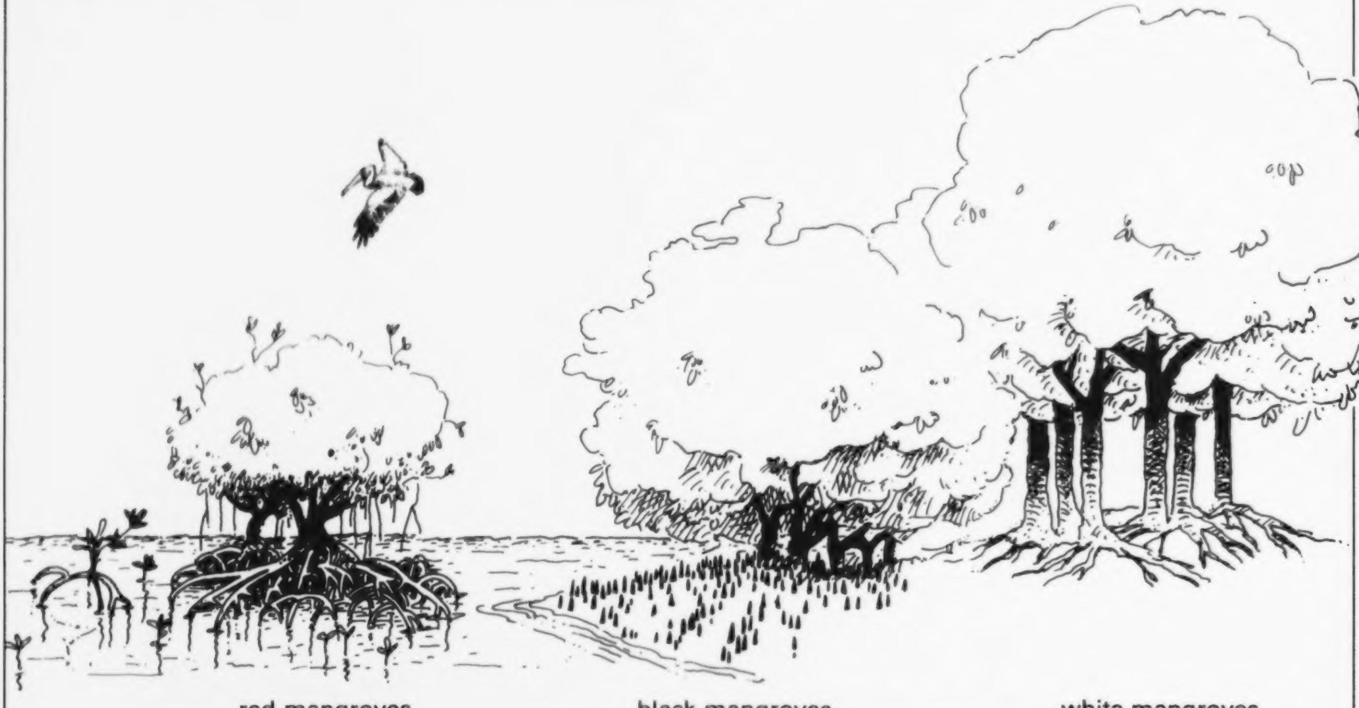
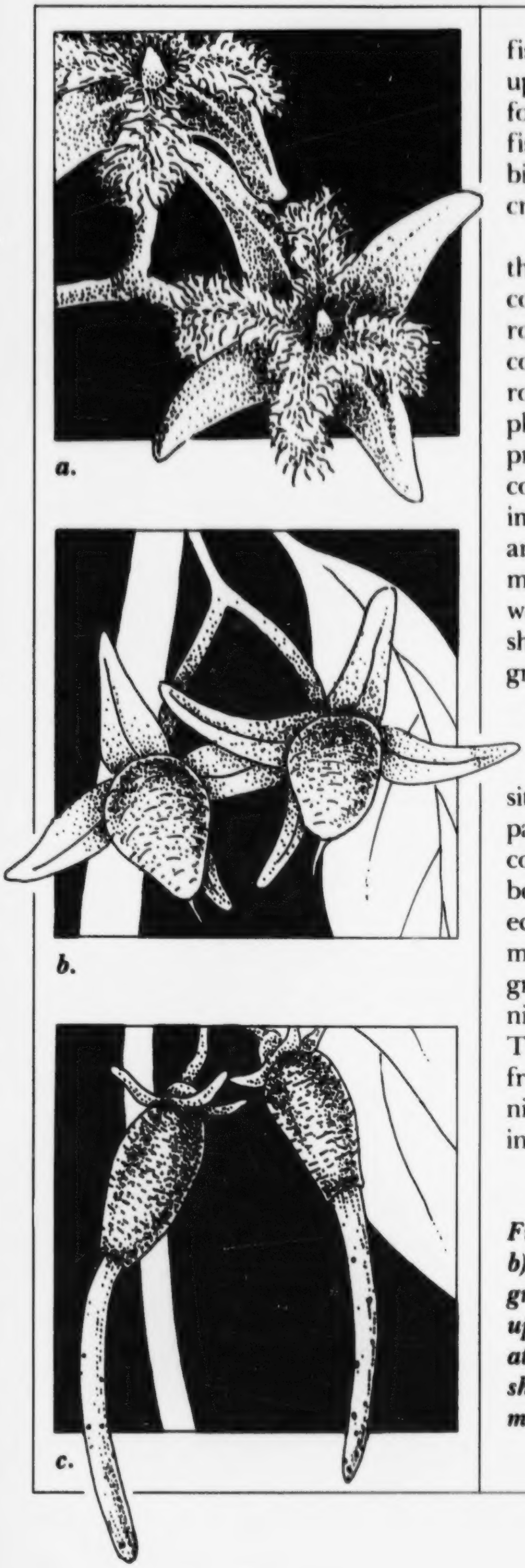


Figure 26: Mangrove forests fringe about 75 percent of the world's tropical coastline. Only three species of mangrove are found in Florida. About 40 species are found in the Indo-Pacific region.



fish. These microorganisms break up the leaf litter, making it edible for still other creatures. Larger fish, turtles, dolphins, and birds, in turn, feed on these creatures.

Other plants also contribute to the productivity of mangrove communities. Algae attach to the roots of mangroves and often cover the sediment around the roots. Various species of phytoplankton contribute to the primary productivity of mangrove communities, although their importance is unknown. Turtle and manatee grass also occur in mangrove areas. In less saline waters other species, known as shoalgrass and widgeongrass, grow.

Although the number of plant species in a mangrove community is small, the diversity of animal species is great. In part, this is because mangrove communities are transitional between marine and terrestrial ecosystems. Such transitional communities, called ecotones, have a greater diversity than the communities lying on either side of them. They may be inhabited by species from each of the flanking communities as well as species not found in either.

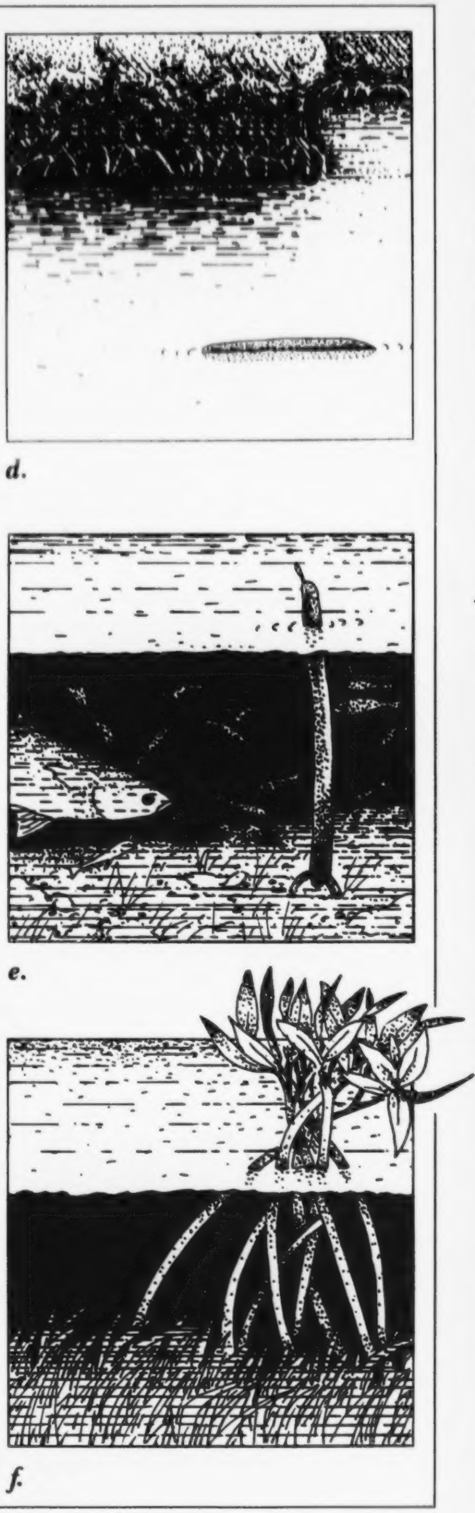


Figure 27: a) red mangrove flower, b), c) red mangrove propagule (seed) growing; d), e), f) after drifting for up to 40 days, the propagule may attach itself to a muddy bottom in shallow water and grow into a mature mangrove tree.

Mangrove communities provide habitat for many invertebrates that pursue a number of different feeding strategies. Filter feeders, which often attach themselves to the prop roots of mangroves, feed upon detritus suspended in the water ***(Figure 28)***. The deposit feeders, various crab and snail species, are mobile and feed upon detritus and algae found on roots and the sediment.

As juveniles, red drum and gray snapper use the protection and abundant food afforded by red mangrove prop roots. As they mature, these fishes migrate to more open water. Killifish and mosquitofish, however, which feed on everything from insects to polychaete worms, are permanent residents of some mangrove communities.

The types of fish in mangrove forests can vary considerably during the year. Heavy rains may so decrease the salinity in mangrove-lined creeks that freshwater catfish and gar may enter mangrove forests. During the dry season when salinity increases, jacks, barracuda, and other saltwater fishes may move quite far up the tidal streams on feeding forays.

Because mangrove forests provide both nesting sites and ample food, they also attract a much more diverse community of birds than do other types of coastal ecosystems. In Florida, over 180 species of birds use mangroves for feeding, nesting, and roosting. These birds include the wading herons, egrets, ibises, and probing shorebirds, such as clapper rails and willets. Cormorants, pelicans, mergansers, and teals are among the floating and diving birds feeding upon fish. Gulls and terns feed both upon fish and invertebrates. Birds of prey, including bald eagles, ospreys, and peregrine falcons use mangroves both for feeding and roosting. The most diverse group of birds, however, are the arboreal (arbor=tree) woodpeckers, flycatchers, and vireos.

Green, Kemp's ridley, and loggerhead sea turtles, bottlenose dolphins, and manatees are some of the larger animals found in channels adjacent to mangrove communities. In Florida, endangered American crocodiles may use thickets of black mangroves for nesting. Most of the sitings of the Florida panther, another endangered species, have occurred in mangrove ecosystems.

Mangroves are valuable as nursery grounds for commercially valuable fish and shellfish, for protection of coastal areas from stormwaters, for the conservation of endangered and threatened species, and for tourism. Recognition of these values can lead to the conservation of these unique marine ecosystems. Because mangrove communities are often ecotones, however, their conservation depends upon the conservation of adjacent ecosystems.

Figure 28: The branches and prop roots of mangroves provide refuge, substrates, and food for a bewildering array of crabs, fish, birds, and other creatures. Mangrove forests are critical to maintaining populations of commercially valuable fish and shellfish and to endangered species.

BEATH

Seagrass Beds

Like mangroves, seagrasses have adapted themselves for life in a marine environment. Unlike mangroves, however, seagrasses are found in temperate as well as tropical areas. They play a dominant role in nearshore ecosystems upon which a variety of endangered or commercially important marine species depend. Like mangrove ecosystems, seagrass beds provide the basis for a food web dependent upon detritus. Like coral reefs and mangroves, seagrasses can substantially alter the physical environment.

The principal species of seagrasses in tropical regions are turtle grass and manatee grass ***(Figure 29)***. In temperate regions, seagrass beds are dominated by eelgrass. Seagrasses have flattened, lance-shaped leaves that block the flow of water. With the slowing of the water flow, small particles carried in the water fall to the bottom. Some of these particles are used as food by animals while others break up and form a mat on the bottom. Below the bottom, seagrasses have rhizomes, rootlike stems which extend horizontally under the substrate and from which new shoots are sent up. These rhizomes help to stabilize the sediment, altering considerably the physical environment of other organisms.

Unlike seaweeds such as kelp, seagrasses are flowering plants and reproduce through fertilization of their small submarine flowers. Water currents carry their pollen and disperse their seeds. Seagrass plants may reproduce in another way as well, when plants become detached from their roots. These plants may float some distance and reestablish themselves elsewhere.

Several abiotic factors influence the distribution of seagrasses. They grow in protected areas such as bays and lagoons where waves may not be great although currents may be substantial. Seagrasses are versatile and may tolerate very salty water (up to 40 parts per thousand) or relatively fresh water. Some species, however, grow better in different levels of saltiness than others and, therefore, are more abundant in very saline or less saline water. Finally, seagrasses develop best where the sediment is relatively fine.

Sea turtles, particularly green sea turtles, manatees, and various fishes graze directly on seagrasses. Green sea turtles, for example, often graze limited areas in seagrass beds, eating only the tops of the plants. This pruning promotes new growth which is nutritionally better food for the turtles. Indeed, meadows of

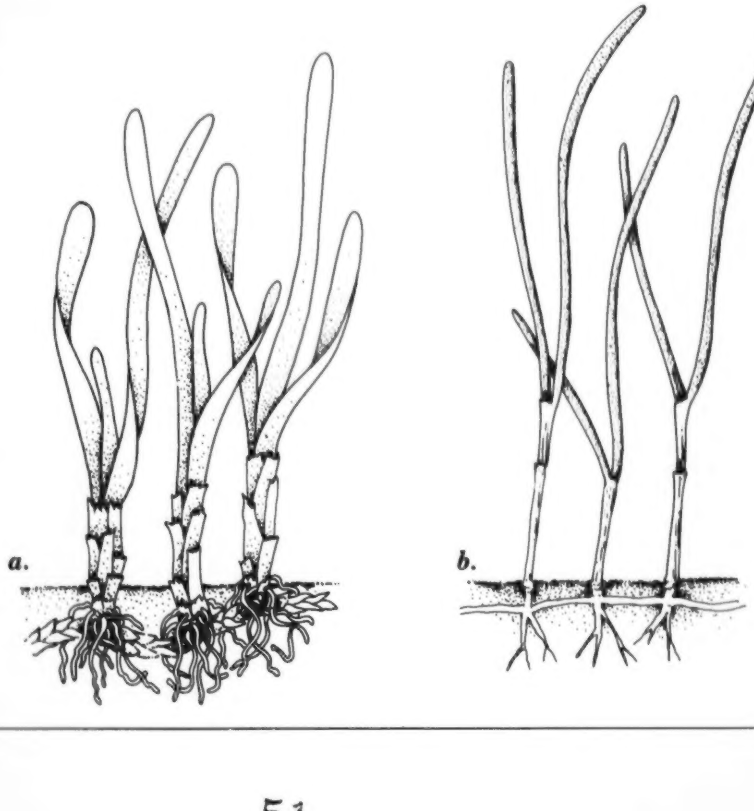


Figure 29: Tropical seagrass beds are favorite haunts of green sea turtles. As adults, these sea turtles eat only seagrasses. a) turtle grass b) manatee grass

seagrass are critical to these animals. Living seagrass also plays a critical role in the diet of a variety of waterfowl, including black brant and Canada geese.

Most organisms are unable to eat the seagrass directly and thus can tap the energy stored by seagrasses only after the leaves have been broken up into detritus by waves and have formed a dense mat on the bottom, where they are further broken up into particles by bacteria and fungi.

Seagrass particles support an array of filter feeding organisms which burrow into the surrounding bottom, live attached to the leaves of seagrasses themselves, or crawl about the bottom. Deposit feeders, such as crabs, shrimps, and starfishes, move about the bottom feeding on particles trapped on the sediments. Burrowing animals, including worms, some molluscs, and mud shrimp, which live with a mate in a permanent burrow, also feed on seagrass particles.

Other animals forage along the bottom. Whole armies of sea urchins and sea cucumbers may advance through beds feeding on detritus that has collected on the mud surface or on the mat formed by broken leaves. Seagrass beds also serve as nurseries for detritus-feeding pink shrimp and, thus, support large commercial shrimp fisheries in Texas and Florida.

Many kinds of organisms use the leaves of seagrasses for attachment ***(Figure 30)***. Among these epiphytes (epi=on, phyt=plant) are anemones, small crabs, bryozoans (byro=moss), and hydroids. Over 100 species of algae also encrust the leaves of seagrasses. Herring and scallops sometimes attach themselves as larvae to seagrass leaves, but after further development they leave the seagrasses.

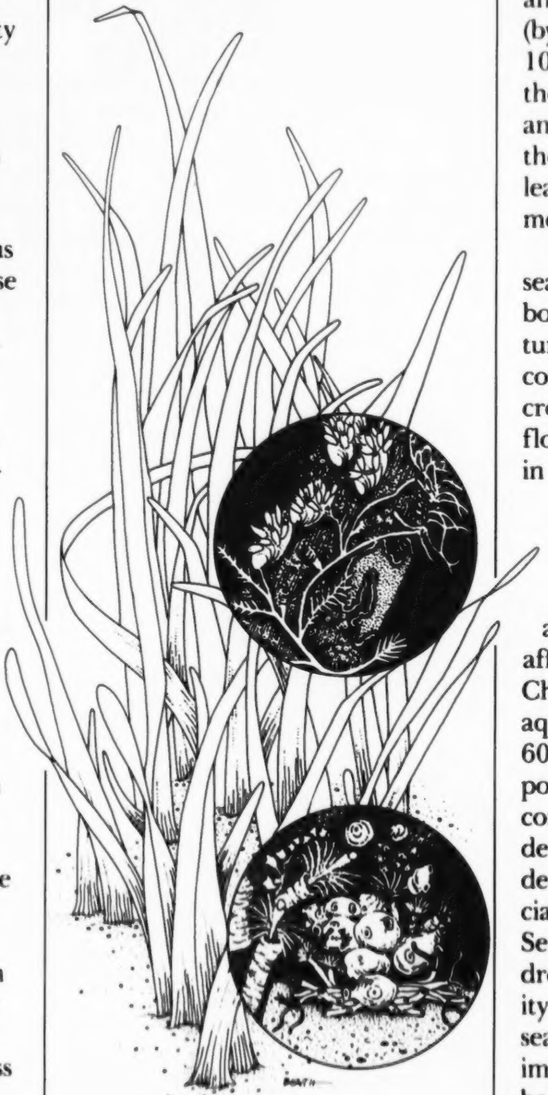


Figure 30: Filter-feeding bryozoans may encrust the leaves of seagrass like moss. Snails, sponges, crabs, and other animals also attach themselves to sea grasses.

Many species of fishes feed in seagrass beds, principally upon bottom-dwelling invertebrates. In turtle and manatee grass areas, common species are mullet and croaker. In more northern waters, flounder and striped bass forage in eelgrass beds.

In both tropical and temperate regions the discharge of sewage and runoff of phosphates and nitrates from agricultural lands can severely affect seagrass beds. In the Chesapeake Bay submerged aquatic vegetation has declined by 60 percent due to the discharge of pollutants into the Bay. This has contributed not only to a dramatic decline in waterfowl, but also to decreasing catches of commercially valuable fish and shellfish. Sewage and silt stirred up by dredging can also reduce the clarity of the water preventing seagrasses from growing. The importance of healthy seagrass beds to commercial fisheries and endangered species argues for exercising particular care when conducting human activities in seagrass beds or in adjacent areas such as mangroves.

CASE STUDY

Looe Key

An ingenious study was conducted of the seagrass beds that intersperse the coral reefs in the Looe Key National Marine Sanctuary ***(Figure 31)***. As noted earlier, seagrass beds are an important source of food for several species of fishes. Some of these, such as parrotfish and surgeonfish, live on coral reefs at night but graze on seagrass during the day. Other species of fish such as grunts and snappers graze on seagrass during the night and remain near the reef during the day.

A scientist investigating the role of seagrass beds and grazers in the area wished to determine the rate of growth of the seagrass and the rate of grazing. In order to determine the rate of growth of seagrasses, the investigator first mapped the sanctuary by sea grass type and density. One square meter blocks (a bit larger than a square yard) were then selected in the middle and on the outskirts of patches of each type of grass. Since seagrasses grow from the bottom and not the top of the blade, the investigator stapled blades of grass where they emerged from the sand. Two weeks later the investigator cut the blades off at the level of the seafloor. That part of the grass blade below the staple represented the amount the blade had grown in the two week interval. With this information the investigator was able to estimate the amount of new growth of seagrass per square meter per day in the patches of seagrass.

The investigator employed an equally elegant technique to discover how much of the seagrass is consumed by fish. He cut all of the grass in selected plots to the same height and stapled individual grass blades five centimeters below their tops, since fish eat from the top of a blade of seagrass. By periodically cutting the tops of the blades of seagrass at the staple and measuring the length of grass above the staple, the investigator was able to determine how much of any individual blade had been eaten. By measuring many segments of grass blades the investigator was able to estimate the amount of seagrass eaten by fish per square meter per day.

This study clearly showed that some fish species on coral reefs adjacent to seagrass beds rely upon those beds for food. Thus, full protection of a coral reef ecosystem requires that the adjacent seagrass beds be protected as well.

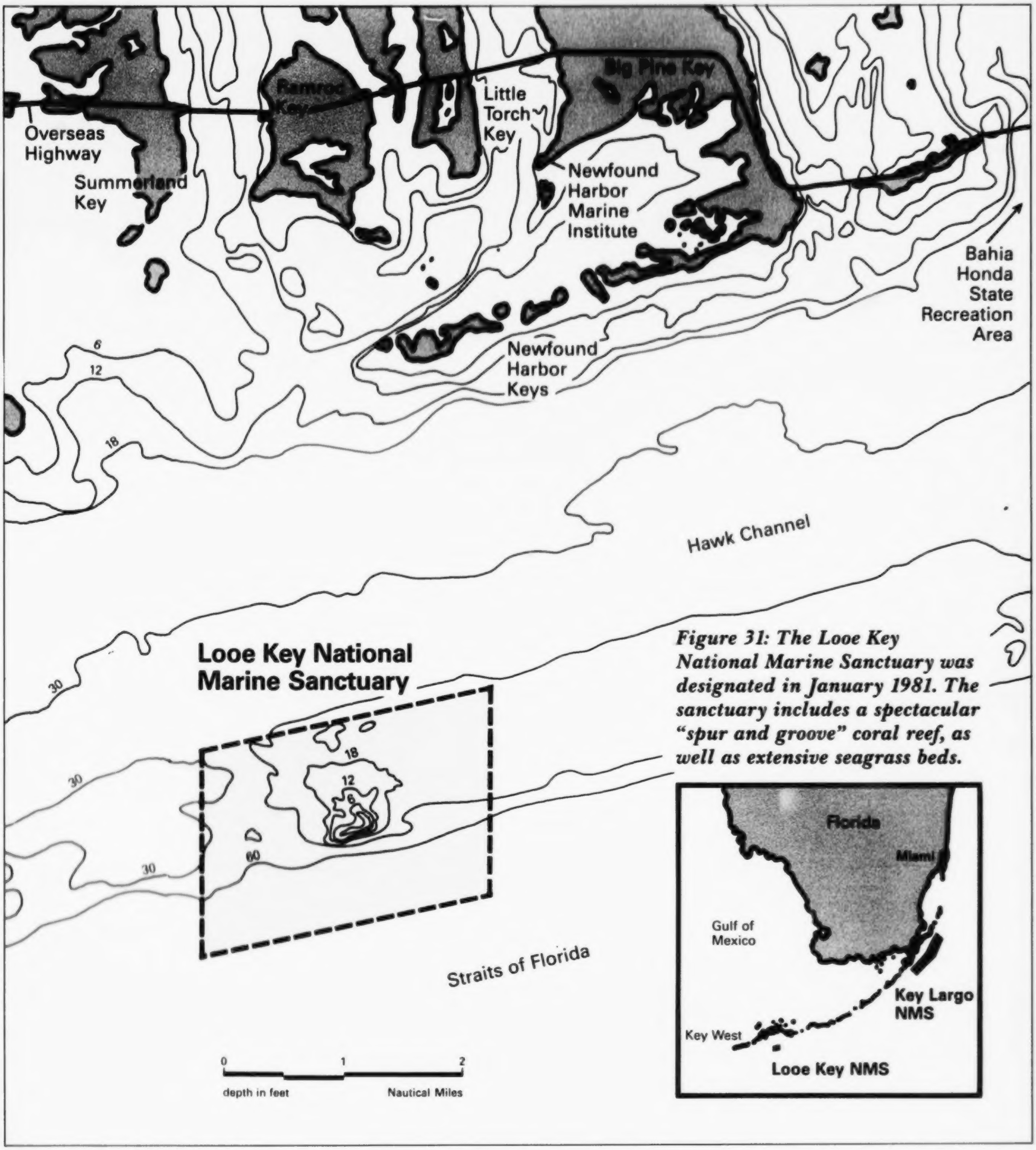


Figure 31: The Looe Key National Marine Sanctuary was designated in January 1981. The sanctuary includes a spectacular "spur and groove" coral reef, as well as extensive seagrass beds.

Coral Reefs

Populated by millions of tiny coral polyps and colorful fishes, coral reefs are the equivalent of tropical rainforests in their diversity of species, complexity, and fragility. In the United States, the coral reefs off Florida and the Florida Keys are the most well known and most frequently visited. Many Americans have also snorkled in the coral gardens of Hawaii. Far fewer Americans, however, are aware of the coral reefs of the Pacific Trust Territories, American Samoa, and Guam which exhibit the even greater diversity of species characteristic of coral reefs of the Indo-Pacific.

Coral reefs are largely restricted to tropical waters. Reef-building plants and animals require clear water, bright light, a stable high salinity, and water temperatures above 70 degrees Fahrenheit. Off the continental United States, coral reefs are restricted to the Atlantic continental shelf in water less than 300 feet deep. Below this depth the zooxanthellae, upon which reef-building or hermatypic (herm=mound) corals depend, do not receive enough sunlight for growth. Zooxanthellae, a kind of microscopic plant that lives within the coral tissue, provide energy to the corals and synthesize protein that enhances the building up of skeletal material. Deeper water corals lack these zooxanthellae and grow relatively slowly.

Coral reefs are built up through the accumulation of the limestone remains of coral skeletons, coralline algae, and other organisms which secrete limestone shelters. Many of these coral colonies look amazingly like plants. In fact, not until 1753 were coral structures recognized as being made up of tiny animals. In fact, corals belong to the same group of animals as anemones, sea fans, jellyfish, and Portuguese man-ó-war. All of these species have tiny stinging cells for capture of prey and for defense.

Coral colonies often begin with a single larva that floats as part of the zooplankton for several weeks until it finds a suitable substrate onto which it may settle. After settling, the larva becomes an adult polyp (=many-footed) and builds a limestone shelter about itself ***(Figure 32)***. In time, the

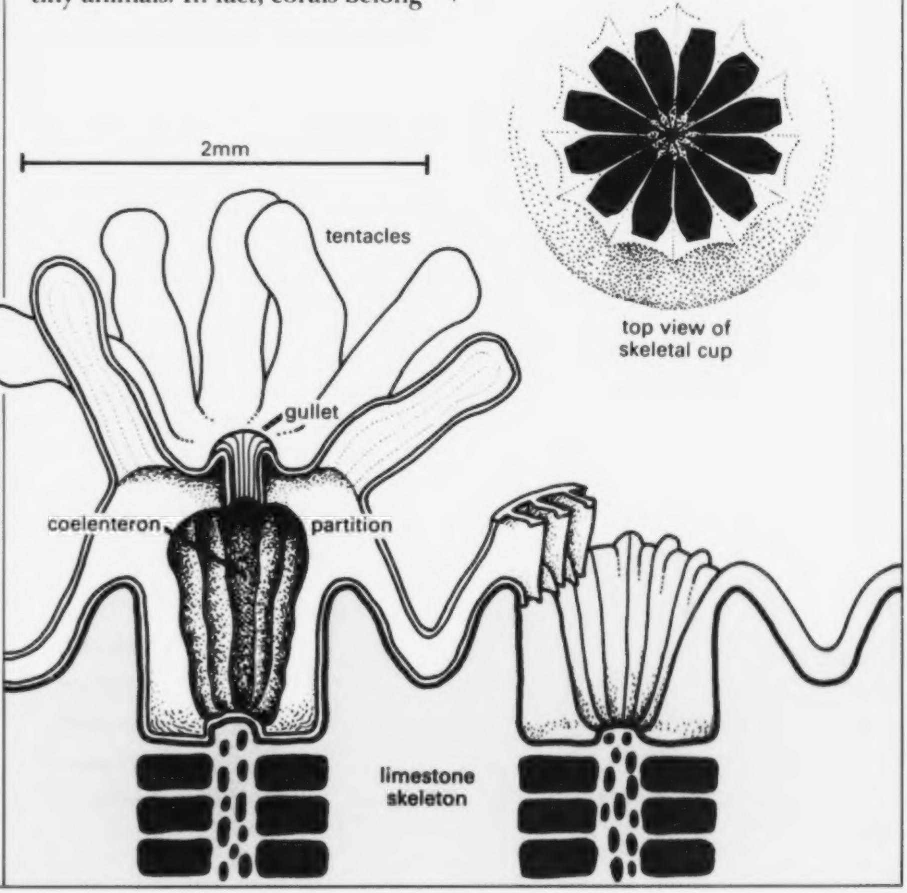


Figure 32: Cross section of a coral polyp. Coral polyps filter food from the surrounding water and pass it into the coelenteron where it is digested.

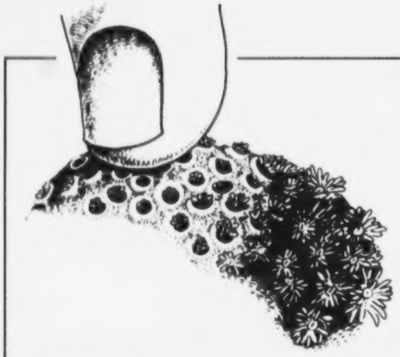


Figure 33: A small structure made up of dozens of coral polyps. Touching coral structures can damage them.

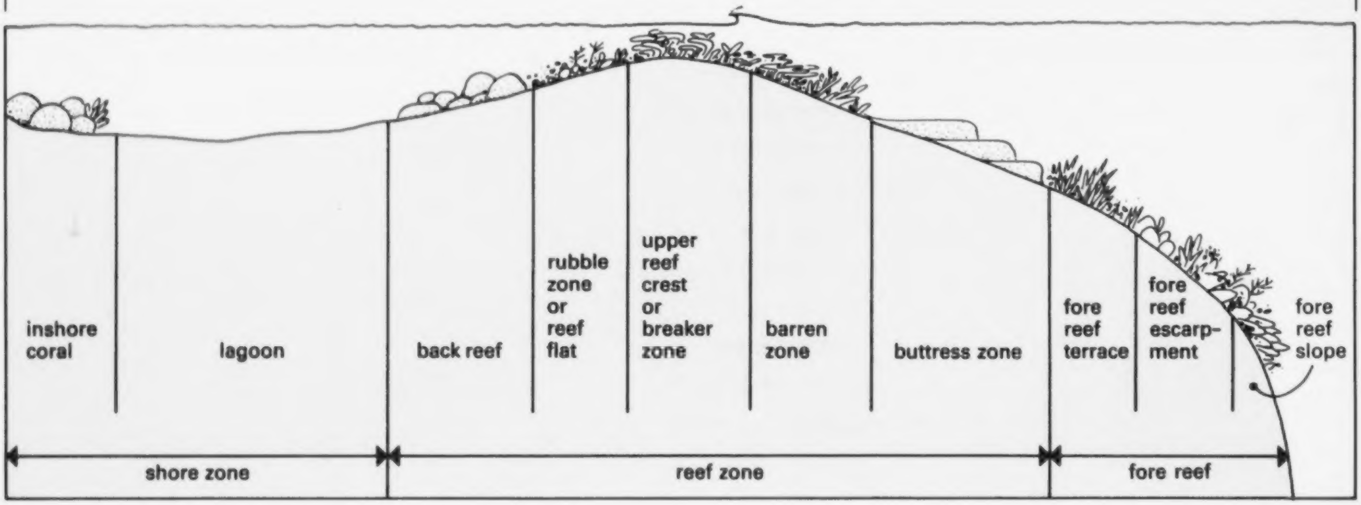
polyp produces a bud which becomes another polyp, also secreting a limestone skeleton about itself. This process continues until a colony of thousands of individual polyps may resemble boulders, staghorns, or fans *(Figure 33)*. Over thousands of years, succeeding generations of polyps leave behind their skeletons and gradually raise the base of the coral reef closer to the surface of the water.

There are many kinds of coral reefs. Fringing reefs are found next to the shore where there is suitable rocky substrate in one to twenty feet of water. A second form of coral reef is the atoll, which is simply a U-shaped or circular reef surrounding a lagoon. Atolls begin as fringing reefs around volcanic islands. As a volcanic island subsides, the reefs become extensive barrier reefs. Finally, when the volcanic island becomes totally submerged, the reefs are left enclosing a lagoon instead of an island. Coral atolls are frequently found along mid-oceanic ridges that are seismically active.

Patch reefs may occur behind or in front of larger reefs, such as fringing reefs or barrier reefs. Patch reefs are generally formed by a few isolated boulders of coral. In areas of volcanic activity, deep patch reefs form on lava flows.

A fourth form of coral reef is the barrier reef *(Figure 34)*. Separated from the land by lagoons, barrier reefs exhibit discrete zones in which different species of corals dominate. Moving seaward, the lagoon bottom gradually slopes up toward the reef crest. This back reef zone is dominated by shallow water species of coral, such as brain coral and star coral, that form flat-topped boulders. On the reef flat or rubble zone that may be exposed to the air at low tide, there is little active hard coral growth. Rather, soft corals, such as fire coral and sea fans, and calcareous algae dominate among rubble of coral which has been broken off in the fore-reef area and carried back onto the reef flat by waves and currents.

Figure 34: Generalized cross section of a barrier reef. Reef-building corals occur only where waters are clear. Such hermatypic corals can substantially alter the physical environment of other creatures.



The upper reef crest receives the brunt of the waves striking the reef and may be dominated by one species of coral. Elkhorn coral, with stout branches pointing away from the waves much like wind-swept trees on a mountain ridge, thrives in the turbulent, wave-dominated environment where sediments are swept away before they can foul the coral polyps. Below the reef crest, elkhorn coral may still grow abundantly, but it changes its form to low, spreading colonies.

Beyond the reef crest other species of coral begin to appear with greater regularity, although they form only patches separated by rubble and sand. At about 25 feet, staghorn coral may dominate, forming tangled patches in which more massive forms of coral may be scattered. Some barrier reefs have a buttress zone in which star coral forms large masses separated by sand channels. The sides of these huge mounds, some of which may be the size of a house, are in shade for most of the time and are covered with other forms of coral, such as the various species of delicate lettuce corals.

Deeper still the reef becomes a terrace on which thickets of staghorn coral, running perpendicular to the shore and separated by sandy channels, stretch seaward. Scattered mounds of other corals are also found on the terrace ***(Figure 35)***. The fore-reef then descends gradually to a zone where star coral are more evident and thickets of staghorn coral become smaller. Sand channels between these patches become broader. The fore-reef slope descends more gradually than the escarpment. Sandy areas dominate along the slope, although pinnacles of coral as high as 35 feet may be found. At the base of the reef, massive corals diminish and soft corals become dominant. The fore-reef slope then drops off precipitously to a zone where there are few corals.

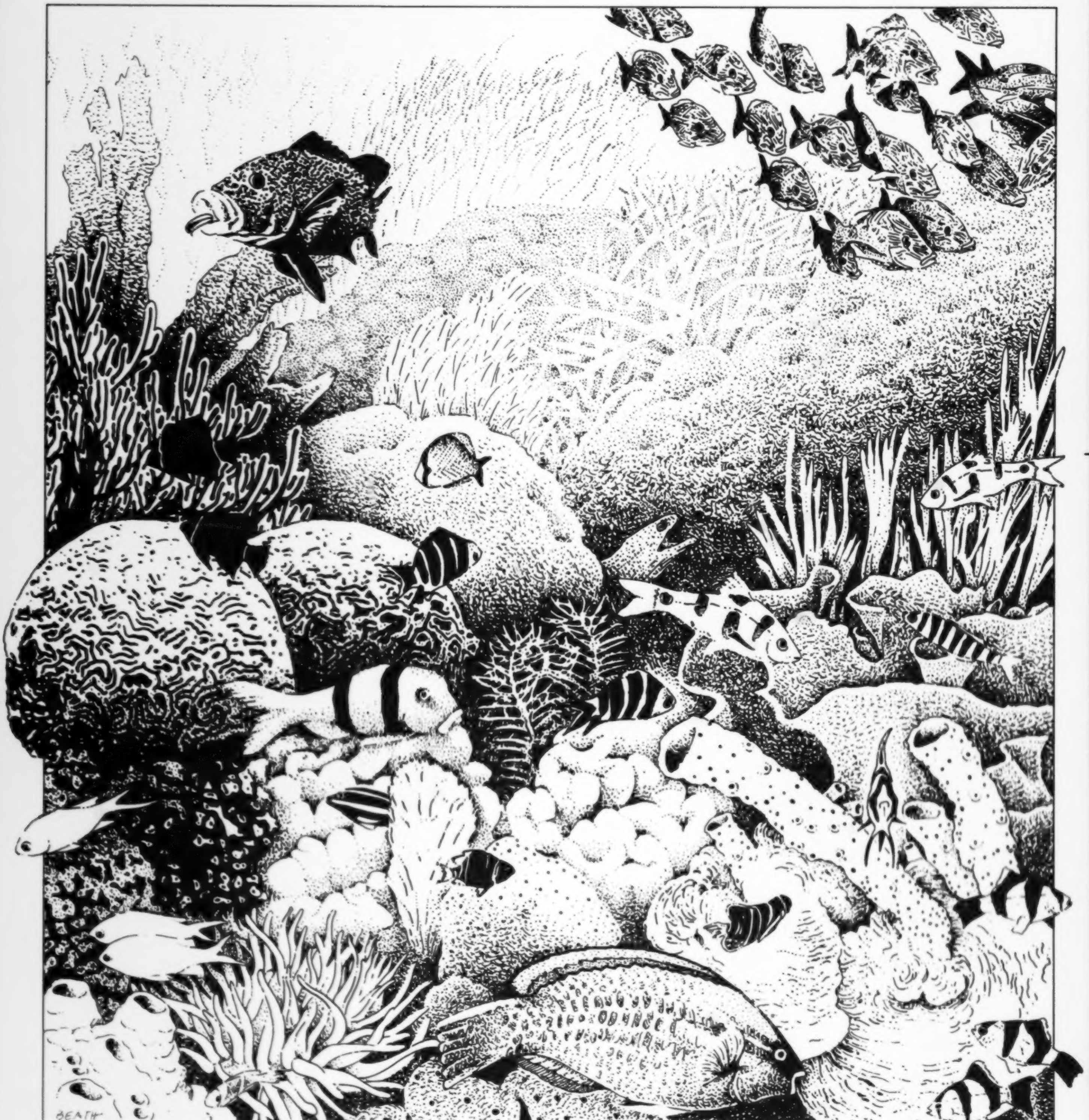
Off Florida and the Florida Keys, bank reefs parallel the continental shelf margin. Moving seaward from the land, a barren rubble reef flat gives way to shallow spur and groove formations dominated by fire coral and golden sea mat. These spurs and grooves descend into deeper water where elkhorn coral dominates. The fore-reef or buttress zone in still deeper water has a diverse assemblage of reef organisms. Large haystack size colonies of star coral dominate. Descending to 135 feet, a low relief hardground is populated with sponges, soft corals, and small stony corals. The reef terminates, in most cases, with a silty sand flat.

Reefs are often intersected by channels through which water carrying sediments and food may flow very rapidly. Such channels help to distribute necessary nutrients, to remove waste, and to oxygenate the water. In their own way, animals which move between the reef and other areas also transport nutrients into and out of the coral reef ecosystem. Thus, like other ecosystems, coral reefs are open systems linked to ecosystems outside them.

The great productivity of coral reefs depends upon the primary productivity of the plants that cover the surface of the reef. Most of these plants are the zooxanthellae in the bodies of coral polyps. In reef flat areas, coralline and fleshy algae flourish. On bare substrate, microscopic algae grow.

The complex web of life on a coral reef can be easily torn. Any substantial decrease in the clarity of water can rob coral of the intense sunlight they require for growth. Runoff of sediments from land can also overwhelm the ability of coral polyps to slough off massive sediment. Heavy use of fish traps can severely reduce many species of fishes, altering the composition of the reef fish community. Careless recreational use can damage coral; anchors and anchor lines can break delicate coral formations. Lastly, the removal of coral for souvenirs or for sale is a problem in many areas. A single branch of staghorn coral may represent hundreds of years of growth by thousands of coral polyps. Fortunately, however, increasing appreciation for the fragile beauty of coral reefs is leading to greater protection.

Figure 35: The fore reef zone includes a broad range of depths and habitats. The shallower, sunlit waters are favored by hard corals. In the deeper, darker waters soft coral dominate.


BEATH

CASE STUDY

Looe Key and Key Largo

From 1978 through 1981, scientists surveyed the fish communities at the Key Largo National Marine sanctuary and at Looe Key, which was under consideration for designation as a National Marine Sanctuary ***(Figure 36)***. The surveys indicated that at Key Largo there was a greater diversity of fishes and a greater number of predatory fishes, such as grouper and snook, than at Looe Key. Some scientists argued that these differences were due to spearfishing, which had been allowed at Looe Key but prohibited at Key Largo since 1961. They argued that the lack of predators allowed species such as grunt and damselfish to compete for available food successfully, while populations of other species decreased as a result. Other scientists, however, argued that the differences between the fish communities at the two reefs could be due to abiotic factors.

Upon designation of the Looe Key National Marine Sanctuary in 1981, spearfishing was prohibited within sanctuary boundaries. In 1982 another fish survey was conducted in the Looe Key sanctuary area and elsewhere in the Florida reef tract. The fish census showed a dramatic increase in predatory fish populations at Looe Key but not elsewhere in the Florida reef tract, indicating that spearfishing before designation of the area as a National Marine Sanctuary had indeed been responsible for the reduced number of predatory fish at Looe Key. Furthermore, the predatory fish at Looe Key no longer withdrew at the sight of a diver as they had when there was spearfishing in the area.

Information from surveys in 1983 indicates that the remigration of the large predators is continuing. Changes in the composition of the prey species have not been detected yet, although it is expected that surveys in future years will find that a new balance between predator and prey at Looe Key will have been reached.

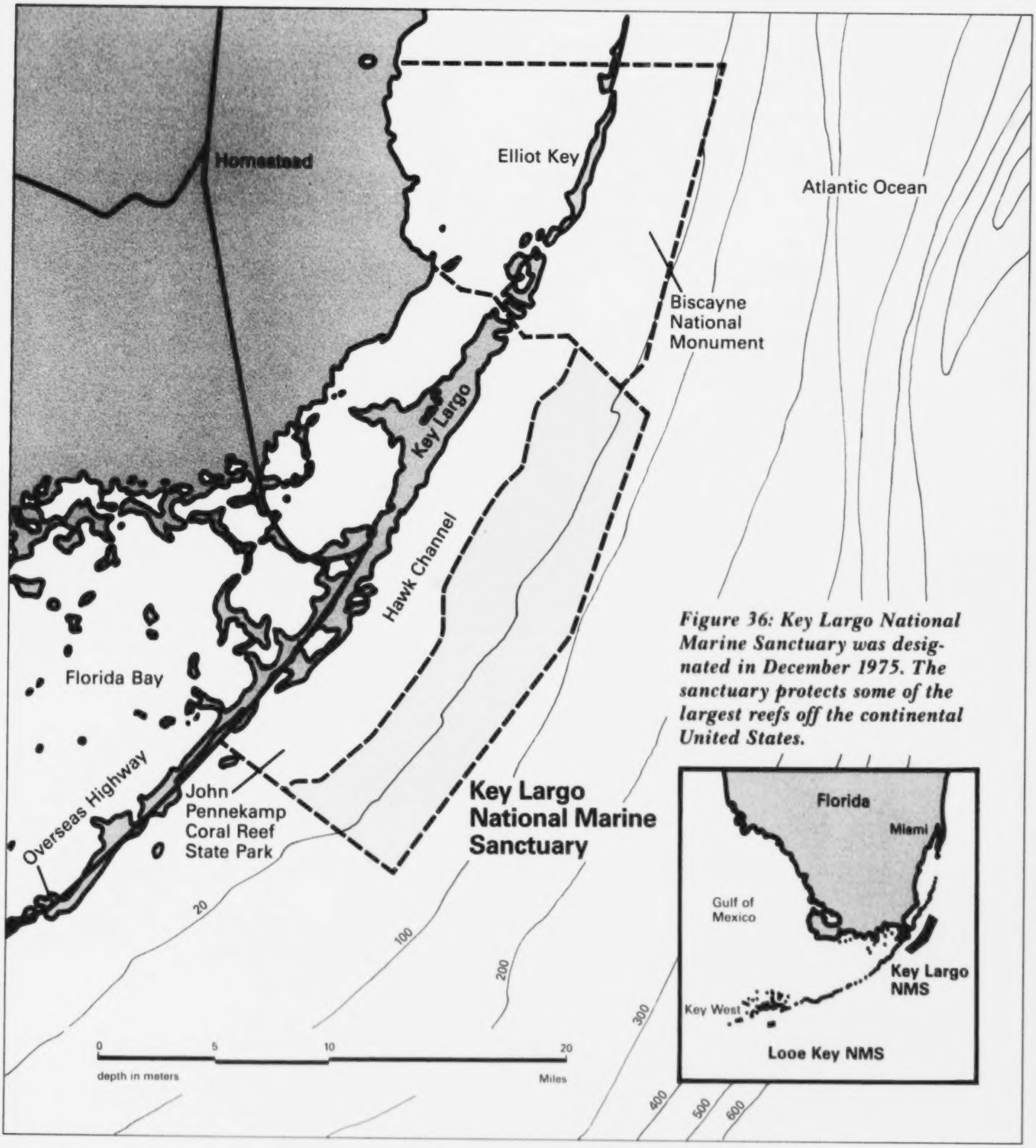


Figure 36: Key Largo National Marine Sanctuary was designated in December 1975. The sanctuary protects some of the largest reefs off the continental United States.

MARINE ECOLOGY

Feeding and Defense Strategies

Life for many animals in the oceans requires an almost constant search for food. As in other marine communities, coral reef organisms have adopted a dizzying array of feeding strategies. At the same time, coral reef animals have developed a remarkable repertoire of defense mechanisms.

A variety of fishes, worms, sea stars, and other animals graze upon encrusting and fixed plant growth on coral reefs. Such grazing may affect the composition of the reef community. For instance, the sea urchin *Diadema* ***(Figure 37)*** grazes on algae and other plant life, making the substrate suitable for settlement of coral larvae. However, because *Diadema* also graze on coral larvae, an excessively large population of *Diadema* may inhibit coral reef expansion just as effectively as a too small population may allow the encrusting algae to cover surfaces suitable for the settlement of larvae.

Some groups of animals are fixed to the bottom and feed upon plant and animal material suspended in the water. Some members of the coral reef community, such as sponges and oysters, extract food from the water by filtering it through their bodies. Sponges, some species of

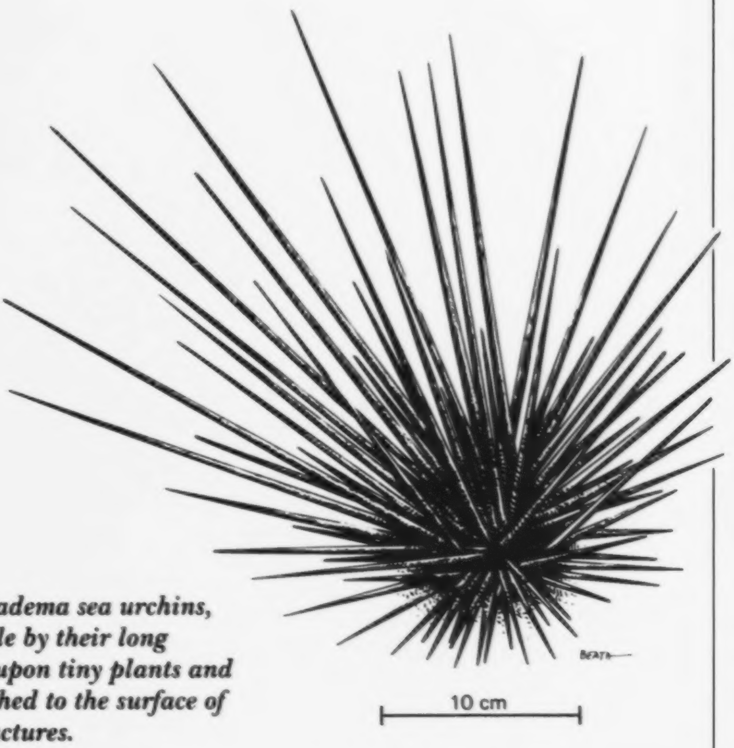


Figure 37: Diadema sea urchins, distinguishable by their long spines, graze upon tiny plants and animals attached to the surface of coral reef structures.

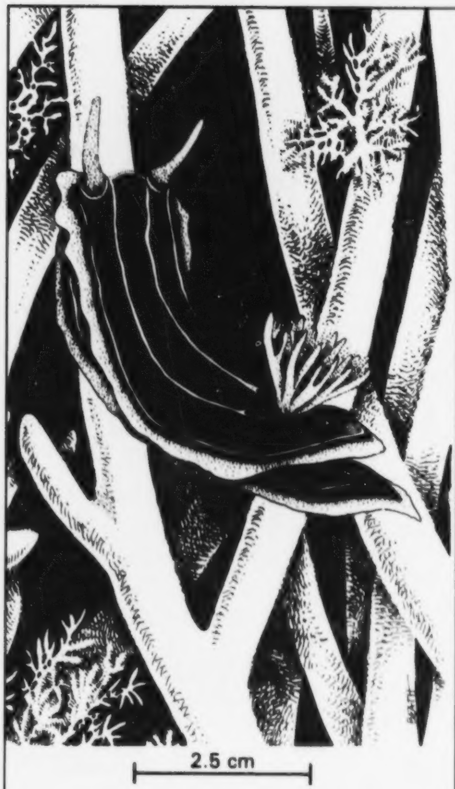


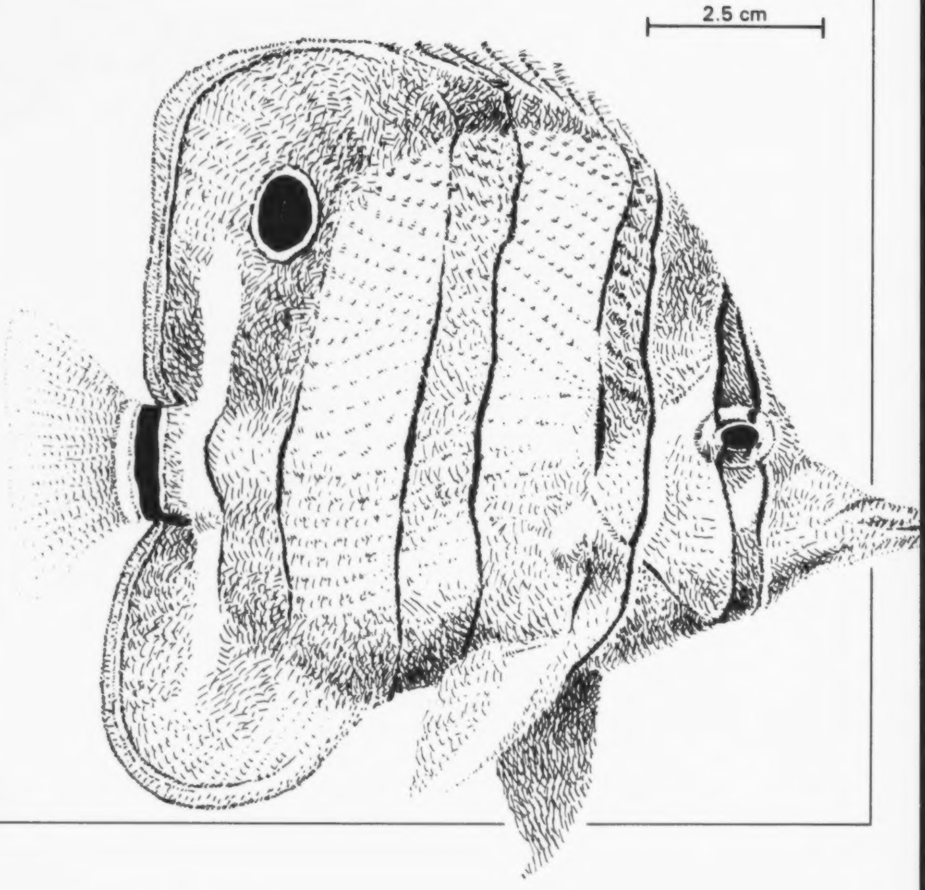
Figure 38: With their gills fully exposed, nudibranchs graze the detritus found on coral structures and on the bottom. Found in many coastal areas, nudibranchs are among the most colorful of all marine creatures.

which may become large enough to hold two people within their cavernous bodies, may filter hundreds of gallons of water through their bodies each day. Some filter-feeders like oysters protect themselves from predators by enclosing themselves in shells. Other species, such as the sea slug and nudibranchs (nud=bare, branch=gill), are not protected by shells ***(Figure 38)***. These brightly colored animals rely instead on their foul taste to discourage predators.

Reef fishes employ a great variety of feeding strategies. Parrotfish use their powerful teeth to rasp off encrusting algae and coral polyps. They then defecate the pulverized skeletons of the coral as sand. It is estimated that a single parrotfish may create more than a ton of sand each year. Butterfly fish have long beaks they use to pry into the many crevices of sponges or coral formations ***(Figure 39)***. Sharks, barracuda, and jacks rely upon their speed to capture prey. Groupers and sea bass, on the other hand, hide in the shadows; when prey wanders by, these fish thrust themselves from the shadows and swallow the prey whole.

Reef fishes are also masters of coloration. Fishes which swim

Figure 39: The false eye of the butterfly fish distracts predators from their true target.



above the reef, for instance, often exhibit obliterative countershading. Their dark upper bodies blend with the bottom when seen from above, while their light lower bodies are virtually invisible against the water surface when seen from below. In the half-light of dawn or sunset these animals become virtually invisible to their prey.

The prey on coral reefs have evolved effective defenses as varied as the strategies of the predators. Smaller fishes like anchovies hover in dense schools above the reef and are exposed to direct attack by swift predators such as barracuda. The schooling behavior, however, makes it very difficult for an attacking predator to select an individual prey, thereby increasing the chances that any individual fish will not be eaten. Sedentary fishes, such as pufferfish or porcupinefish, are covered with spines and can inflate themselves, making them a painful meal at best ***(Figure 40)***.

Other species of fishes may use disruptive coloration to fool approaching predators. Strong stripes break up the outline of such fishes as snapper and drum; these fishes are very difficult for a predator to see against the irregular background of a reef ***(Figure 41)***. Butterflyfish display a false eye near their tail; predators, aiming for this false eye, end up overshooting the mark as their prey heads off in the direction opposite what the predator expects.

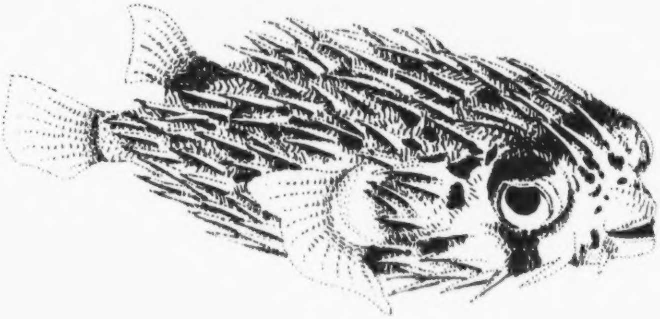
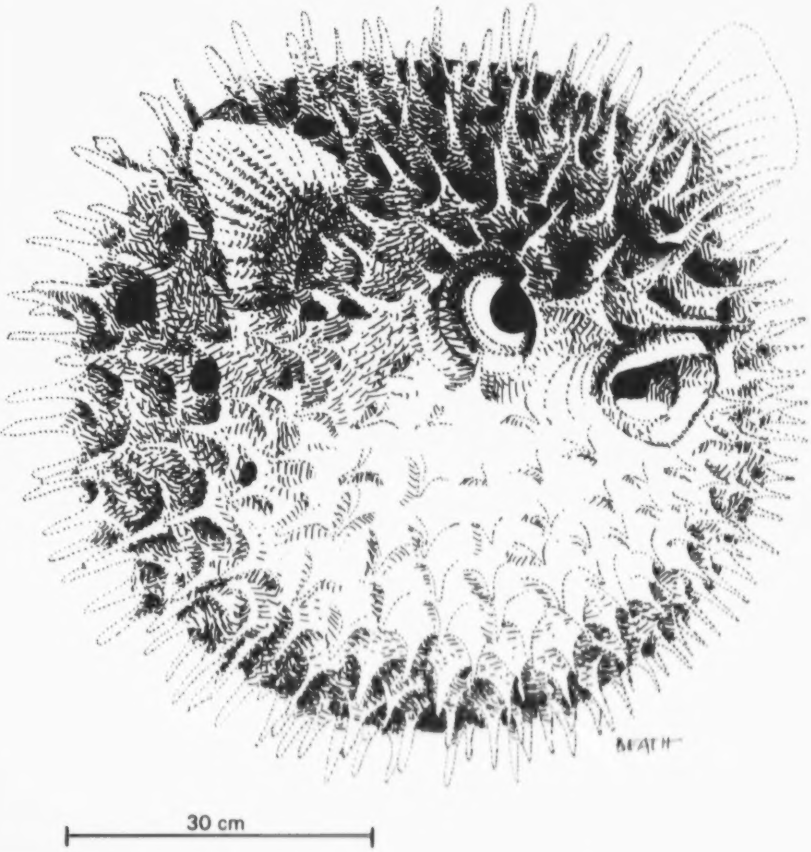
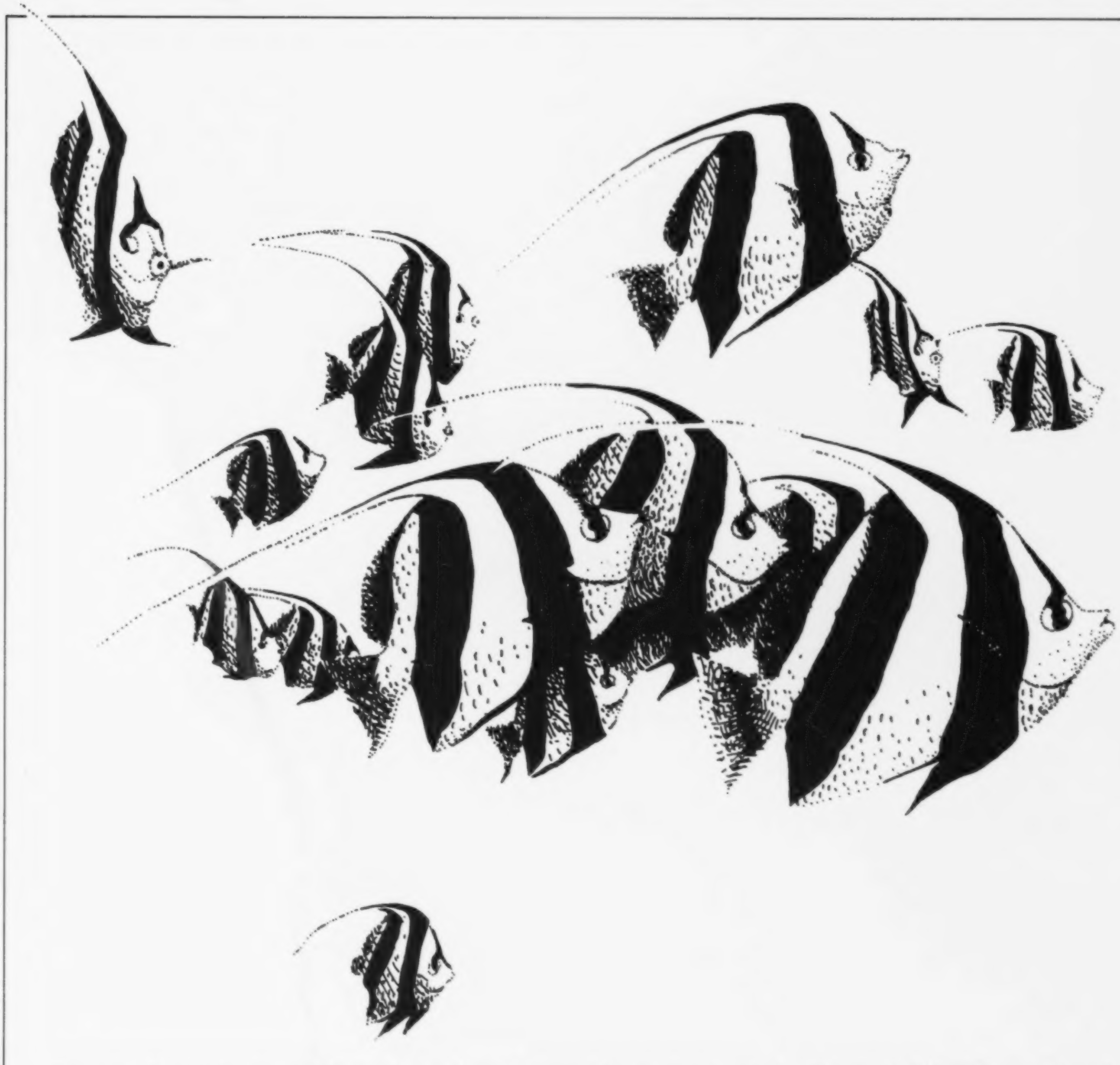


Figure 40: When threatened a porcupinefish will expand itself into a ball of painful spines.





Some reef organisms are able to change their coloration. An octopus can assume not only the coloration of its surroundings but also the form of sponges or coral. In the end, an octopus may let out dark dye to cloud its escape. Some species of octopus have even developed an ability to emit a phosphorescent cloud of light at night.

Figure 41: Like other species of fishes in coral reef and other ecosystems, false Moorish idols find protection in numbers and in their camouflaging stripes.

Perhaps the most fascinating types of relationships among animals are called symbiotic (sym=together, bio=life). In many cases, both species benefit from, even depend upon, such relationships ***(Figure 42)***. For instance, colorful fish called wrasses eat parasites on the bodies of much larger fishes, which might otherwise be expected to eat the much smaller wrasses. The wrasses obtain food while the larger fish, such as bass, are cleaned of parasites. Some crabs inhabit worm burrows where the worm pumps water in and out to obtain food and oxygen. The crabs gain the protection of the burrow and a steady flow of water from which they too can strain food. These and other symbiotic relationships play a significant role in the economy of marine ecosystems.

While the organisms on a coral reef display particularly interesting adaptations for feeding and defense, similar techniques are used by animals in other marine ecosystems. The study of these adaptations is among the most interesting in the marine world.

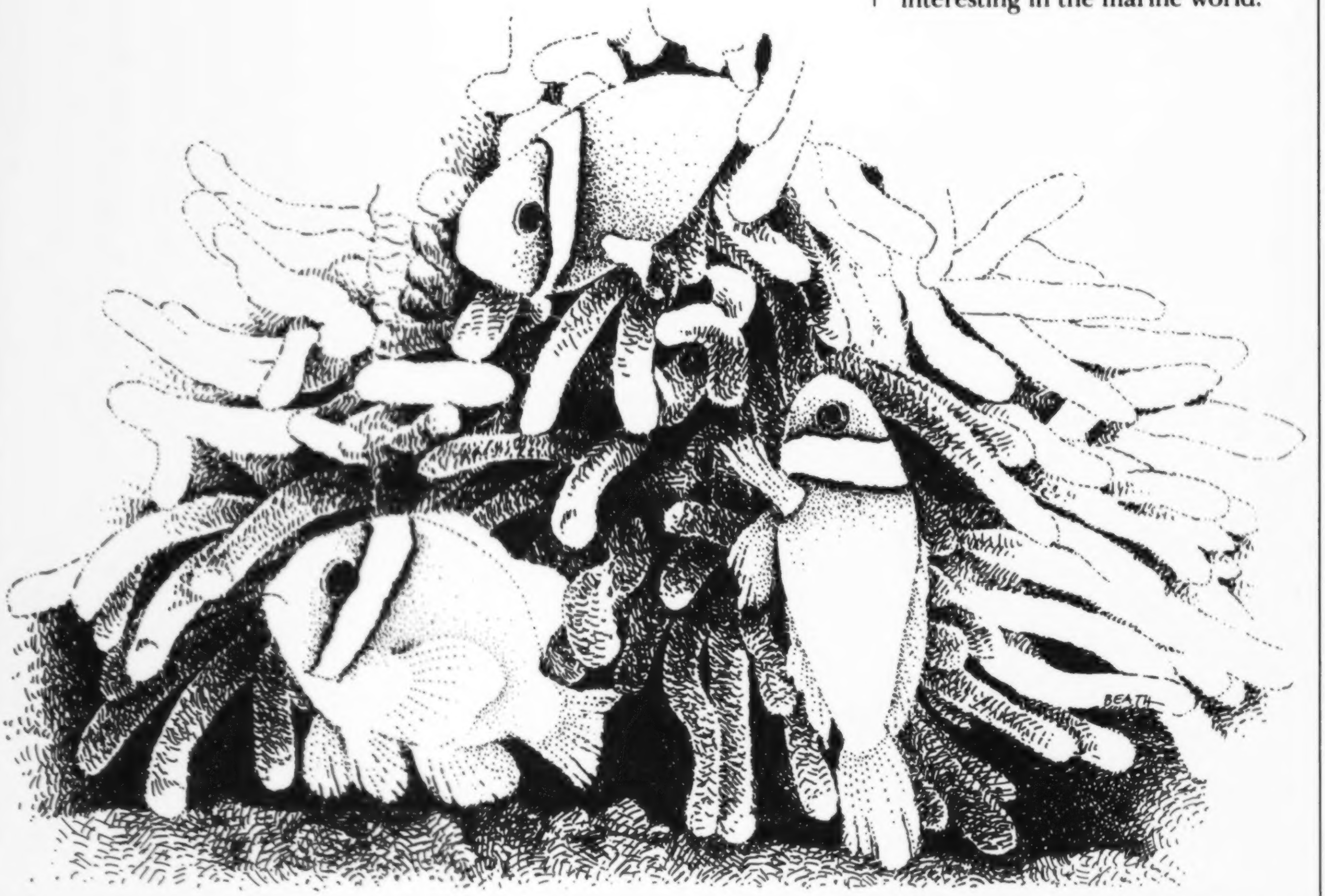


Figure 42: After ritualistic self-introduction, a damselfish may gain the "trust" of a sea anemone. A mucus on the scales of these damselfish make them immune to the stings of the anemone's tentacles.

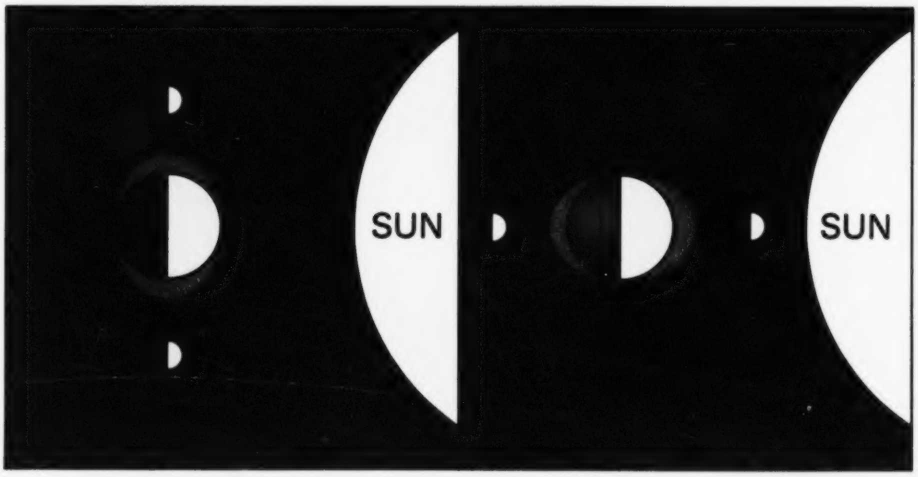
NEARSHORE TEMPERATE ECOSYSTEMS

The tides ebb and flow over many different surfaces, ranging from the muds of quiet coastal lagoons and the sands of popular bathing beaches to the rocky cliffs and boulder beaches of the shores of Maine and the West Coast ***(Figure 43)***. Each of the surfaces, or substrates, presents different problems to the creatures living on them. In some instances the problem is how to hold on to the substrate while being continually pounded by waves. In others it is how to get food or to find others of the creature's own kind in order to be able to reproduce. Nature has found a variety of solutions to each of these problems.

The area between the high tide line and the low tide line is called the intertidal zone. The challenges of living in the intertidal zone are enormous. When the tides go out, organisms living in the intertidal zone literally are left high and dry. As the tides change, waves often smash across the intertidal with great force, threatening to wash away or crush anything not firmly attached or buried. Variations in heat and light also cause stress to the organisms of the intertidal zone.

In the temperate regions of the United States, the two most extensive intertidal ecosystems are the rocky intertidal and the sandy intertidal. Even though rocky and sandy intertidal habitats are often found immediately adjacent to one another, they share virtually no species between them, a mark of how different these two types of ecosystems are.

Figure 43: The gravitational pull of the sun and the moon cause the water in the oceans to bulge, creating low and high tides. The highest high tides and the lowest low tides (spring tides) occur during the new and full moons.



Beyond the intertidal zone are coastal waters that host very productive ecosystems. Shallow parts of the coastal seas are home to vast aggregations of marine life ranging from the commercially important flounders and rockfishes to seals and seabirds.

The high level of nutrients is the primary factor that distinguishes these temperate coastal ecosystems from others. Because of the nutrients washed into the sea from the land by rain and rivers, temperate coastal ecosystems are naturally highly productive. Their shallowness and temperature enhance this productivity: the temperature of the water is not so cold that it causes stress to marine creatures, nor is it so warm that it interferes with production.

Kelp forests and seabird and pinniped rookeries are three especially interesting examples of these ecosystems. Found at various points along the west coast, and in the case of seabird rookeries, along the Atlantic coast as well, they provide dramatic examples of the interrelationship between the physical processes of the coastal environment and the lifeforms in the region.

Sandy Intertidal

The intertidal habitat most visited by people is the sandy intertidal. This is the beach between the high and low tide marks. Visitors sometimes see beach crabs and a few other animals such as sand fleas and beach hoppers, but very few people are aware of the sometimes vast numbers of animals which may be hiding beneath their feet. For example, scientists investigating a central California beach determined that at the height of abundance there were over 3,400 invertebrate animals beneath a one square yard area of sandy beach. Most of these animals were tiny crabs and worms, with some clams and shrimps mixed in. In most cases the number of animals living in the sands will be much lower.

Sandy beaches are subject to severe and rapid changes in temperature and moisture. Sea water reflects, diffuses, and absorbs the energy of the sun. As the tide goes out the sand loses the protective cover of water and the exposed sand heats up under the direct rays of the sun. At the same time, the moisture content of the uncovered beach begins to drop, due to both the removal of the overlying water and the effects of evaporation.

The animals in this habitat protect themselves from the heat and the drying of the sun by burrowing into the sand. As the beach heats up and dries out they dig deeper to cooler, wetter areas. By burying themselves in the sand, they also are protected from predators, even the long-billed shorebirds, which probe the sand for the living food hidden there. At night, when many predators are asleep, the beach is alive with hoppers that are ready to dive into the sand and tunnel to safety at the approach of an intruder.

Some of the animals of the sandy intertidal zone are able to burrow with extraordinary speed, sometimes even emerging between waves to grab some food and then reburying themselves as the next wave approaches. Others dig less fast, relying instead on their thick shells to shed the force of the waves.

Sand crabs bury themselves just below the surface of the sand, with eyes and a pair of antennae protruding. As waves wash over the crabs, they extend another set of featherlike antennae to strain out the tiny animals and plant particles floating by. As the tide moves up and down the beach, the sand crabs move with it, staying in the area where the waves break on the beach.

Most animals in the sandy intertidal are found in zones. The most important determinant of this zonation is the effect of the tides, although as the sand crab demonstrates, waves and other factors have their effects on species zonation ***(Figure 44)***. From the high tide line down to the mean water line, one finds burrowing shrimps, burrowing isopods (especially the air breathing pill bugs), and worms, especially bristle worms. Below the mean water line down to the low tide line are found razor clams and Pismo clams, as well as burrowing mole crabs and worms.

As in other marine ecosystems, the physical environment of sandy intertidal areas changes from day to day and from season to season. But other kinds of changes can be catastrophic. For instance, the fierce storms that battered California during the winter of 1982-1983 removed large areas of sandy beaches. It is still too early to tell whether these beaches will reestablish themselves. Also, imprudent coastal development in this and other areas of the United States has increased the natural instability of sandy beaches, leading to the disappearance of beaches and the investment of millions of dollars in beach restoration projects that attempt to prevent the inevitable from occurring.

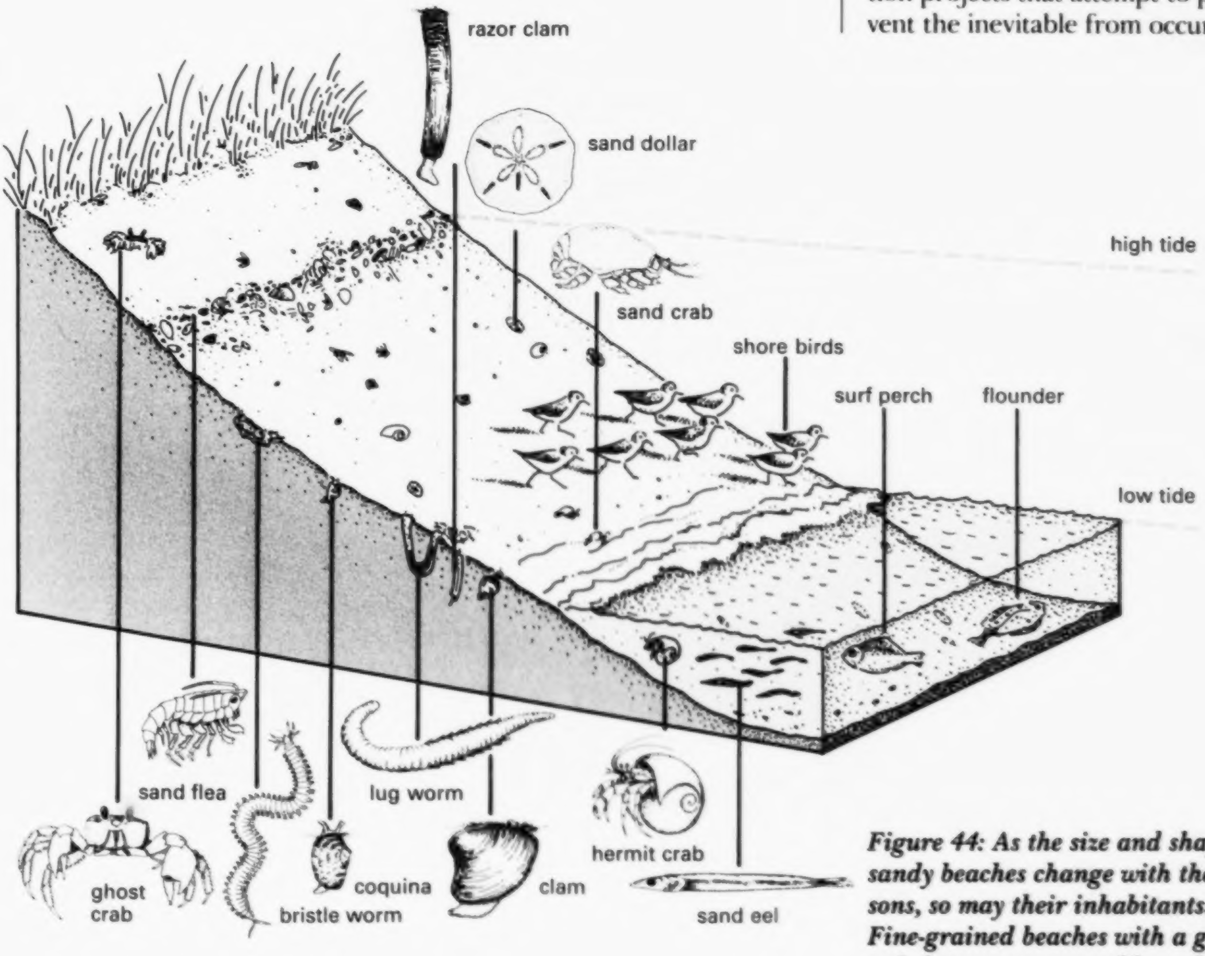
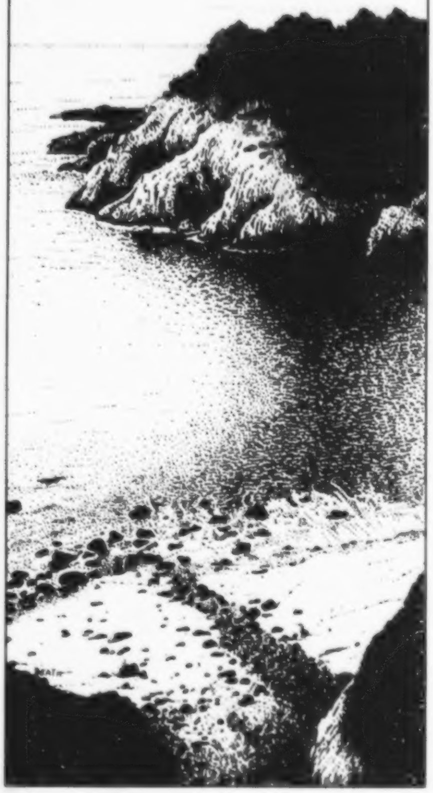


***Figure 44:** As the size and shape of sandy beaches change with the seasons, so may their inhabitants. Fine-grained beaches with a gradual slope are more stable and have more animals of more kinds than other beaches do.*

CASE STUDY

San Miguel and Santa Cruz Islands



The Channel Islands National Marine Sanctuary surrounds the northernmost of California's Channel Islands ***(Figure 45)***. The coastline of these islands is characterized by steep rocky cliffs punctuated by occasional sandy pocket beaches ***(Figure 46)***. A study of some of these beaches made in the late 1970's shows the factors affecting the distribution of animals in the sandy intertidal.

The scientist conducting the study found that the physical characteristics of the beaches were the greatest determinant in the distribution of beach animals. One of the most important of these characteristics is the size of the sand grains. Beaches with fine sand generally have a greater abundance of animals than those with coarse sand. Grain size, in turn, can be affected by a number of things. A steep slope can mean that fine grains are easily lost to even mild waves. Changes in the seasons often change the grain size of sandy beaches, with summer weather and current patterns depositing fine sand and winter weather and currents removing it. Basically, the more stable the beach, the finer the grain size and the more abundant the animals.

Another important factor is the temperature of the sand. As with grain size, temperature changes with the seasons. Warm weather favors certain species over others, as does cool weather. As the seasons change, then, even on beaches with little seasonal variation in grain size, the abundance and kinds of animals change.

This suggests physical changes in sandy beaches result in frequent changes in the populations and species composition of the animals living in the sand. As a consequence, animal species that have evolved to live in the sand must be highly mobile. If they were not, they would quickly become extinct when winter storms or hot summer temperatures changed the physical environment of the beach. This would mean that eventually there would be beaches without life. Fortunately, beach creatures are mobile, and beaches usually have abundant, if hidden, animals living beneath their surfaces.

Figure 46: Sandy beaches are probably the marine ecosystems with which people are most familiar. They are certainly among the most interesting because of the variety of challenges they present to animals and plants and the different ways organisms have found to cope with these challenges.

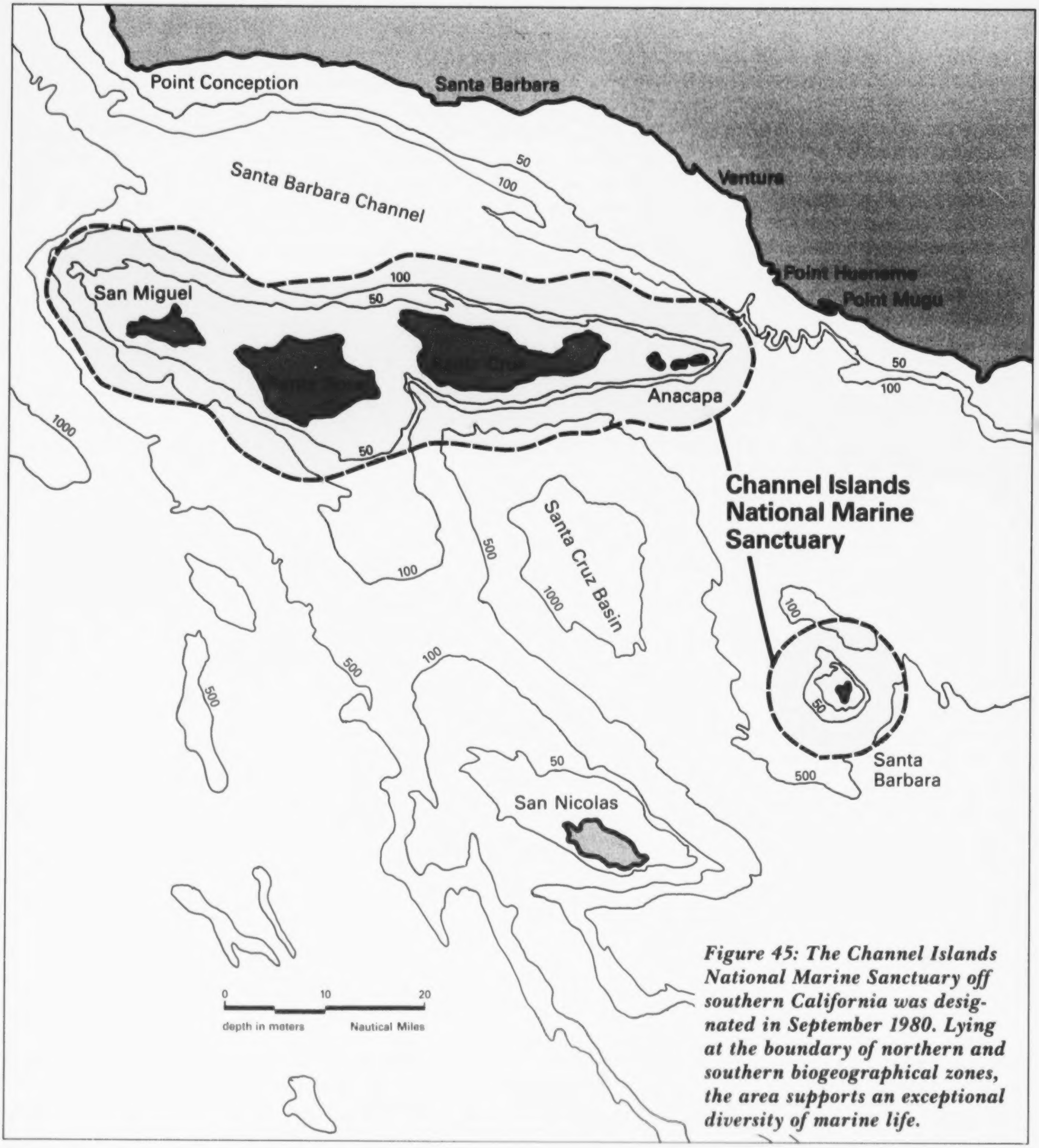


Figure 45: The Channel Islands National Marine Sanctuary off southern California was designated in September 1980. Lying at the boundary of northern and southern biogeographical zones, the area supports an exceptional diversity of marine life.

Rocky Intertidal

The rocky intertidal is a particularly challenging environment for ocean life. Yet rocky coasts are the homes of myriad small creatures such as mussels, barnacles, sea stars, crabs, anemones, and a host of marine algae like sea lettuce, purple laver, and feather boa kelp.

A person who looks at a rocky intertidal area for any length of time will soon be struck by the zonation of the plants and animals found there ***(Figure 47)***. It is as if someone had drawn a series of horizontal lines on the rock face creating several distinct bands, then assigned organisms to the various bands and told them that if they dared to cross the lines they would die for their mistakes. Actually, that is not far from the truth. The lines are not drawn by a human hand, but by the tides and waves. The sun and air enforce them.

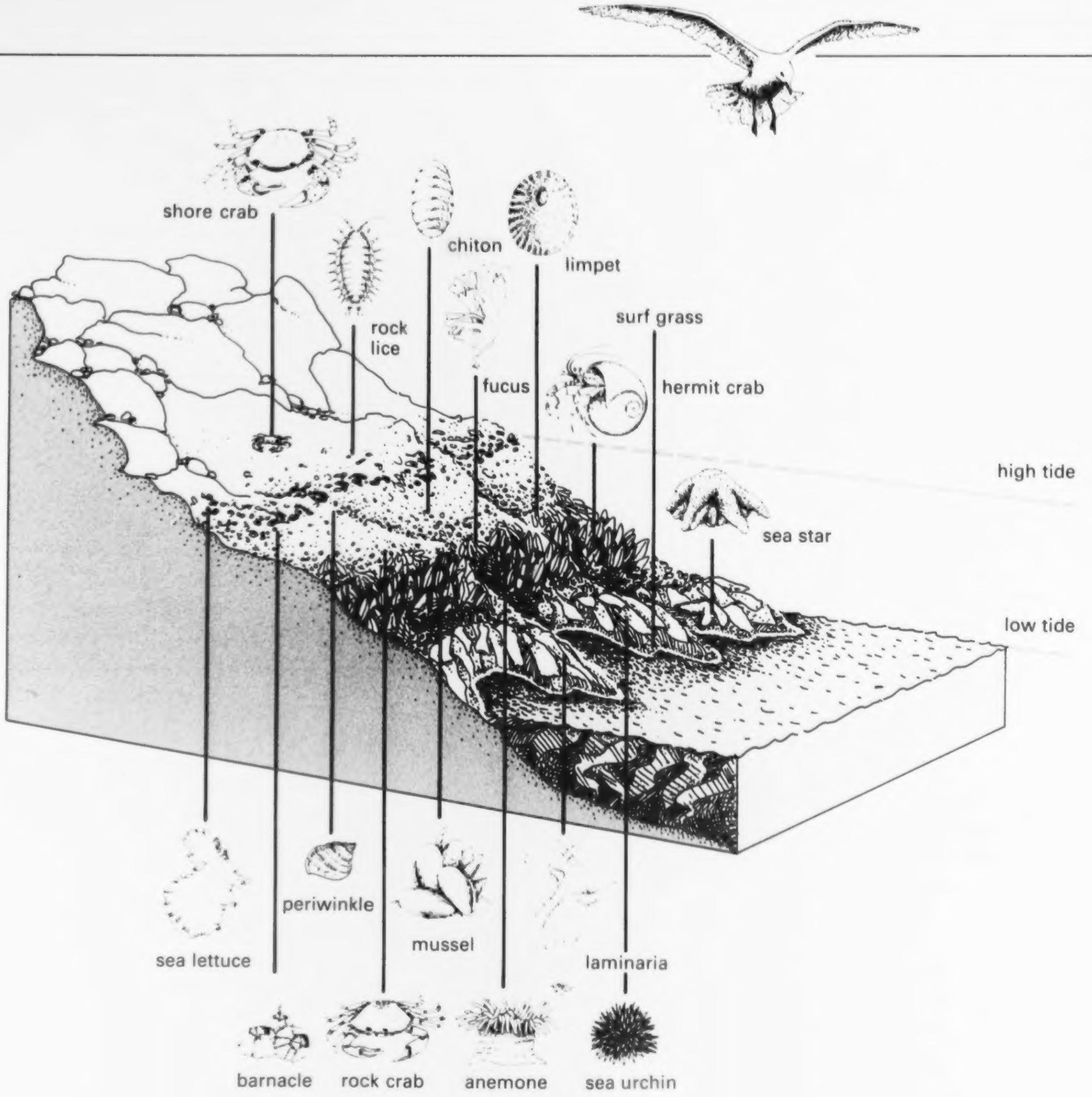
As the tides rise and fall and the waves strike and splash the rocks, the tolerance of the creatures is tested. Organisms that can survive prolonged exposure to air are found in the uppermost zones. Organisms at the lowermost zones need to be wet almost constantly. Desiccation, or drying out, is combatted in some animals, such as mussels, limpets, and chitons, by holding a small amount of water around the body when the tide is out. Snails fight desiccation by withdrawing into their shells and tightly capping the opening with a protective lid, or by cementing themselves to a rock. Exposed seaweeds have no way to protect themselves other than to be tough. Some seaweeds turn crisp and lose up to 90 percent of their water during the course of a single tidal cycle, then regain water on the next high tide with no ill effects.

Another way of fighting the drying effects of air is to hide from it. Some species hide under thick canopies of seaweed in a small world where darkness and moisture prevail. Similar habitats are found in crevices and cracks in the rocks. Species that would die if uncovered by the tides in an exposed location thrive in these protected microworlds where the climate is entirely different from that of the adjacent rock.

Another significant abiotic factor is the type of substrate. Species that are unable to endure the heat and drying effects of direct sunlight are unlikely to be found on a clean, smooth sandstone substrate. They will be found, instead, in the cracks and crevices of substrates like granite. Also, sand lifted by waves may scour rocks, leaving them virtually devoid of life. Even small seaweeds can have this effect as waves sweep them back and forth across the face of the rocks.

In addition to these abiotic factors, a number of biotic factors affect the distribution of species in the rocky intertidal. There can be intense competition among different species and within species for suitable substrate. The ability of an organism to move about will determine whether it can move to areas that are favorable as conditions change. However, an organism that has ventured outside of its normal zone may find, as it struggles to cope with a degree of wetness or dryness for which it is unprepared, that life is difficult. If an organism is able to survive the stresses of a strange zone, it may find itself at the mercy of predators unknown in its home zone or may not be able to find others of its own kind in order to reproduce. Leaving one's own zone usually means death.

There are positive forces at work in the rocky intertidal as well. The moving water constantly renews nutrients. It also brings in rich supplies of oxygen, flushes away waste products, and provides protection from predators. These positive factors are sufficient to cause the intertidal zone to be blanketed with dense mats of animals and plants.



The uppermost zone, called the splash zone, is rarely covered by the tides. The primary wetting agent in this zone is the spray from waves. Organisms common to this zone are rocklice, a few barnacles, and periwinkles. Seaweeds generally are not found here because they cannot protect themselves against the drying effects of the sun and wind as can these animals with their hard outer shells.

Figure 47: Environmental factors, such as changing tides, air temperature, and exposure to sunlight, affect the distribution of plants and animals in the rocky intertidal.

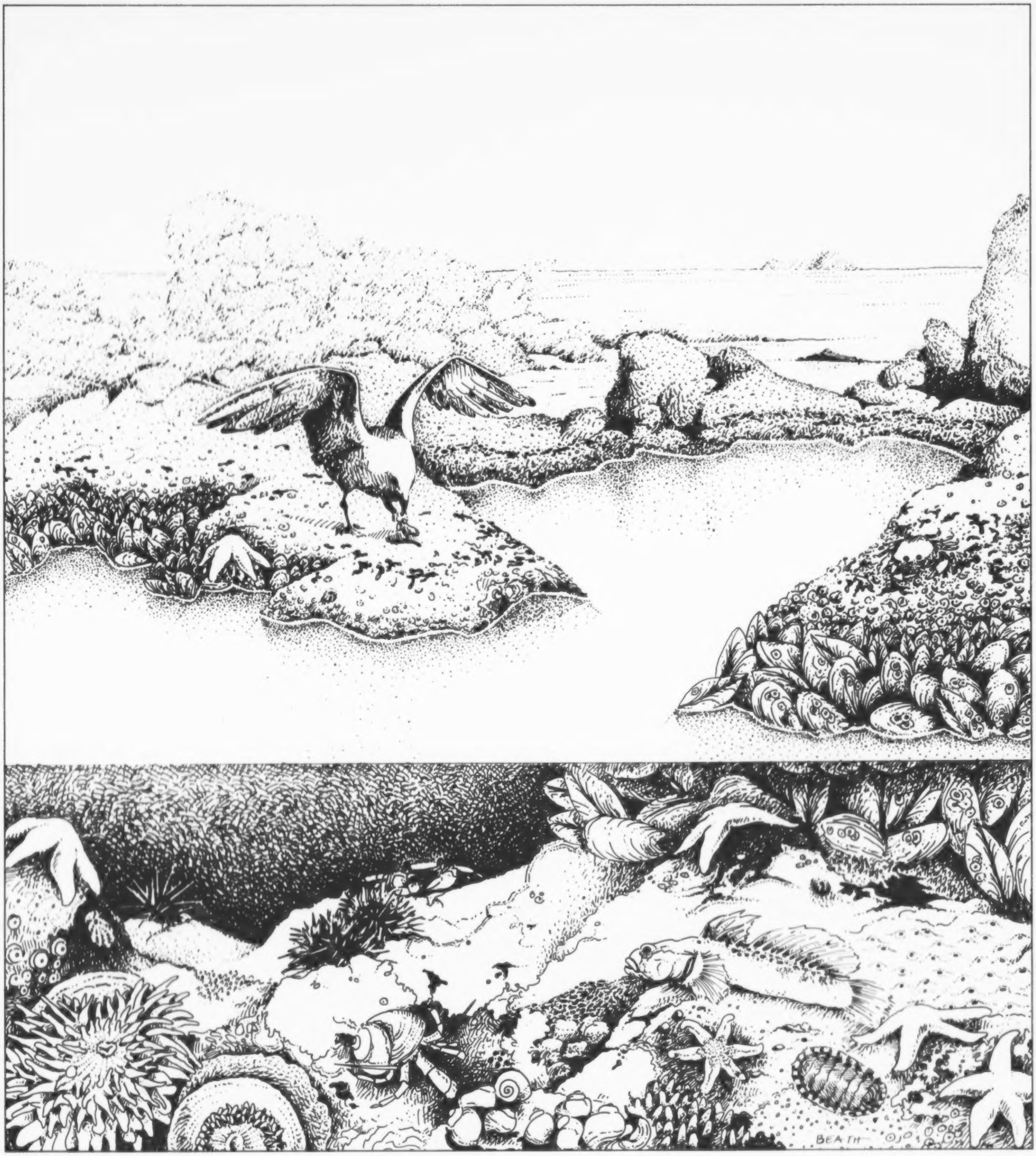
The next zone is regularly exposed to the air but it is also regularly covered by the tides and waves. This zone, just above the mean water level, is the highest level at which seaweeds are found, some kinds of which give this zone one of its common names, the rockweed zone. Other seaweeds and various species of shellfish, including barnacles, limpets, periwinkles, and shore crabs also live in this zone. In protected bays this zone is sometimes referred to as the oyster zone due to the presence of these shellfish.

The next zone is below the mean water level but above the low tide level. Called the mussel zone or the midlittoral zone, this area is characterized by beds of mussels attached to the substrate by strong fibrous moorings, called byssus threads, secreted by a special gland. Life in this zone is a teeming mass of shellfish and seaweed. In some places the rocks are carpeted by great masses of small anemones. Among the dominant mussels, anemones, or other shellfish are often found limpets, sea stars, rock crabs, shore crabs, hermit crabs, turban snails, and chitons.

The lowest intertidal zone is bared only by the lowest of low tides. It is sometimes referred to as the seagrass zone. Much of the habitat of this low zone is covered by seaweeds, among which live a vast army of anemones, snails, sea stars, sea urchins, abalones, and sponges.

The rocky intertidal zone is subject to another set of factors affecting species distribution: the effects of humans. People often come to this area to experience the beauty of the meeting of land and sea ***(Figure 48).*** Unknowingly, they sometimes end up trampling well-camouflaged animals and plants and disturbing shy ones. They turn over rocks to see what is under them, causing the death of many animals and plants. Sometimes in the interest of learning more about the intertidal or keeping some of the beauty for themselves, they collect specimens of what they see. Of even more importance is the removal from the rocks of some favorite food items such as abalones, mussels, and limpets. These activities, often well intentioned, can quickly result in the destruction of large parts of the rocky intertidal.

Figure 48: Tidepool communities are among the most accessible and easily disturbed of marine ecosystems. One can learn a lot about these communities from quiet observation.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CASE STUDY

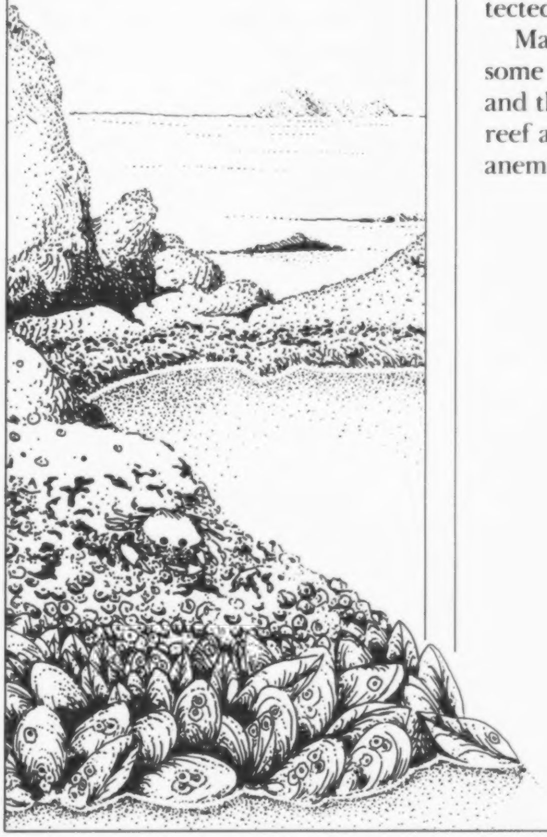
Duxbury Reef

In the Point Reyes-Farallon Islands National Marine Sanctuary near San Francisco there is an area of rocky intertidal habitat known as Duxbury Reef ***(Figure 49)***. Not a coral reef but a low-lying 66-acre shale shelf, Duxbury Reef is noted for its outstanding populations of intertidal invertebrates, especially barnacles, turban snails, and limpets, and for an outstanding mussel bed. Also in the reef habitat are anemones and various seaweeds, including surf grass.

Scientists have been studying Duxbury Reef regularly for many years. Because of this, they have a good idea of how the marine life of the reef has changed as visitation has grown. They have divided the reef into three areas, two of which are close to parking lots and access trails. The third area is more remote and cut off by dangerous channels which can flood and trap unwary visitors in deep rough water. Because of its relative isolation, the third area gives a good indication of what the other two areas would be like if they were not subject to human disturbance.

A comparison of the three areas shows that animals in the less protected areas do not get a chance to become as large as they would if left undisturbed. Large animals attract attention to themselves by their size and they become targets for collectors and others. Thus the less protected areas are devoid of large animal specimens.

Many large invertebrate animals do exist in the third area, including some large mussels. Two giant individual animals, one a green anemone and the other a keyhole limpet, have been observed in the protected reef area since 1949. Researchers have even given them names: the anemone is "Tony" and the limpet is "Owly."



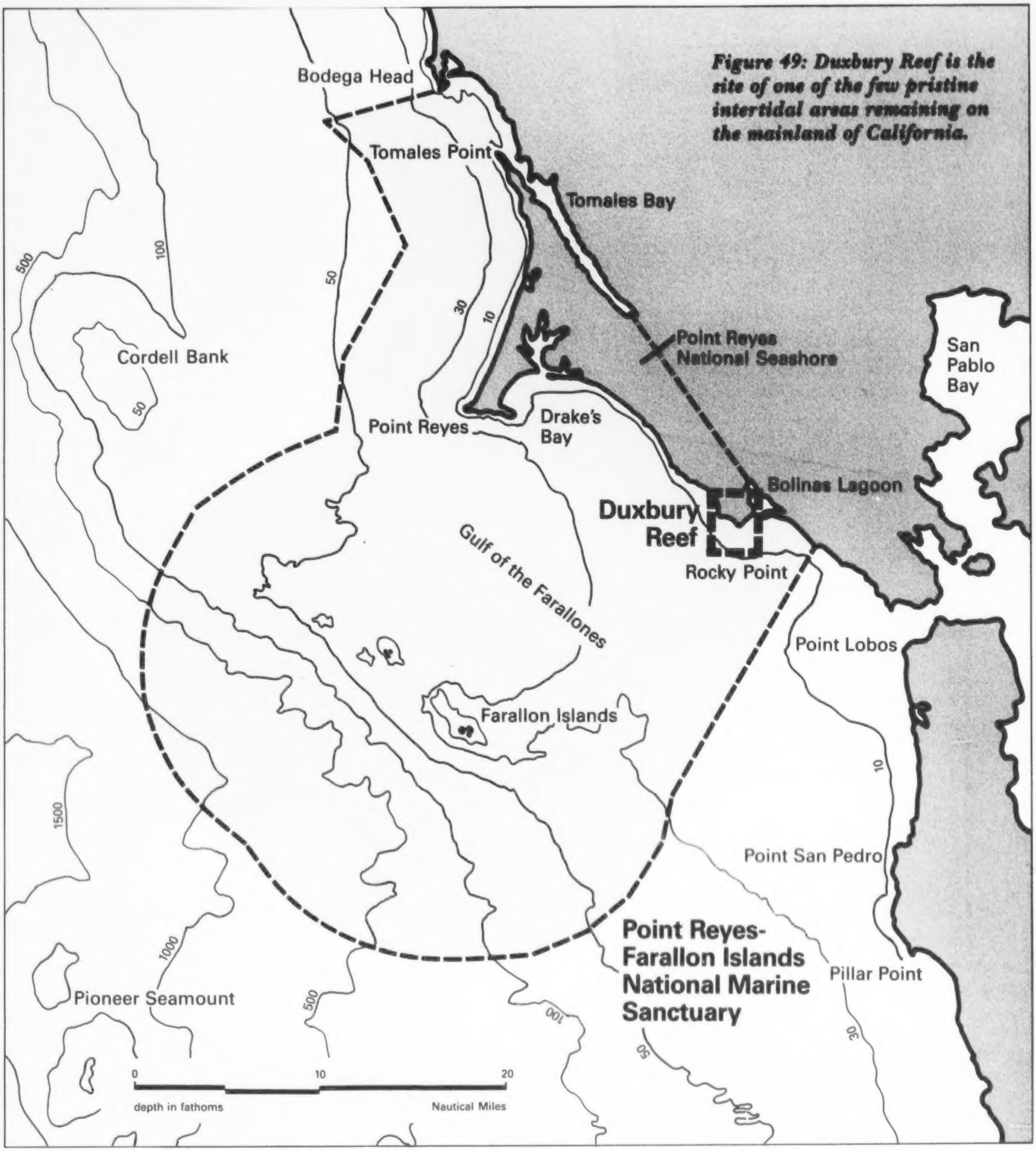
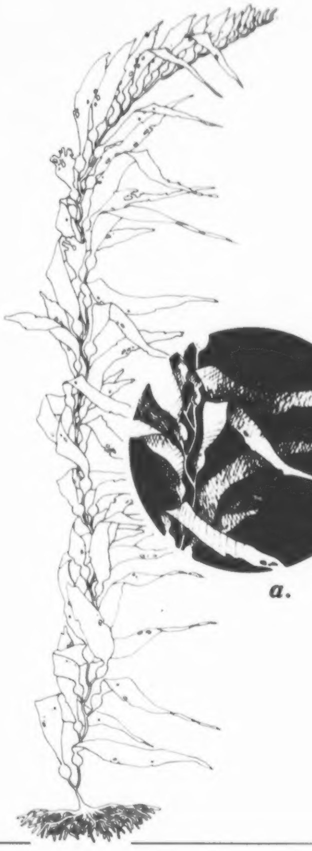


Figure 49: Duxbury Reef is the site of one of the few pristine intertidal areas remaining on the mainland of California.

Kelp Forests

On the west coast, from the Mexican border up to Alaska and as far as the Aleutian Islands, kelp beds are sometimes found in waters shallow enough for light to penetrate to the bottom. These kelp beds shelter millions of individual animals of hundreds of species. Different kinds of kelp are found on the east coast, but these species do not form the giant beds characteristic of west coast forms.

Kelp beds are similar to forests and jungles. Kelp plants, like trees, provide hiding places, roosting areas, food, and substrate for a variety of animals.



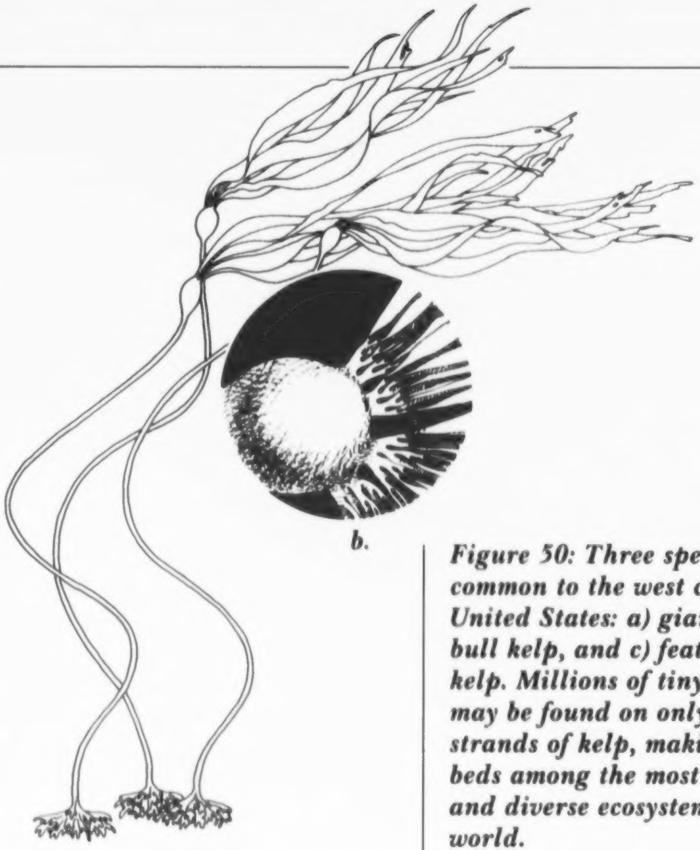


Figure 50: Three species of kelp common to the west coast of the United States: a) giant kelp, b) bull kelp, and c) feather boa kelp. Millions of tiny animals may be found on only a few strands of kelp, making kelp beds among the most productive and diverse ecosystems in the world.

Fish swim from frond to frond and plant to plant much as birds fly from bough to bough and tree to tree. Shrimps and crabs wander about the plants, searching for scraps of food, much as insects swarm over trees.

When scientists refer to kelp they are actually referring to several different species of large, fast growing marine algae ***(Figure 50)***. Kelp beds off southern California, for instance, are primarily made up of giant kelp, while bull kelp is dominant from Monterey to Alaska.

These species of kelp are sometimes found together and with other types of kelp including feather boa kelp. Giant kelp is a plant with several long stipes, or stems, each covered with brown leaf-like fronds that have small gas bladders that provide flotation. Bull kelp, in contrast, has a bare stipe terminating in a large gas-filled float with long brown fronds radiating from the float. Each kelp plant is anchored to hard, rocky substrate by a tangled holdfast. The plants stretch where the water spreads their fronds to catch the energy-laden rays of the sun.

c.

As in other ecosystems, one finds zonation in kelp beds. Instead of zones based on the tidal levels of water, kelp beds are divided into the canopy habitat where the kelp fronds are the thickest, from the surface down to about ten feet, the mid-kelp habitat located between the canopy and the area just above the bottom, and the holdfast region, located on the bottom itself.

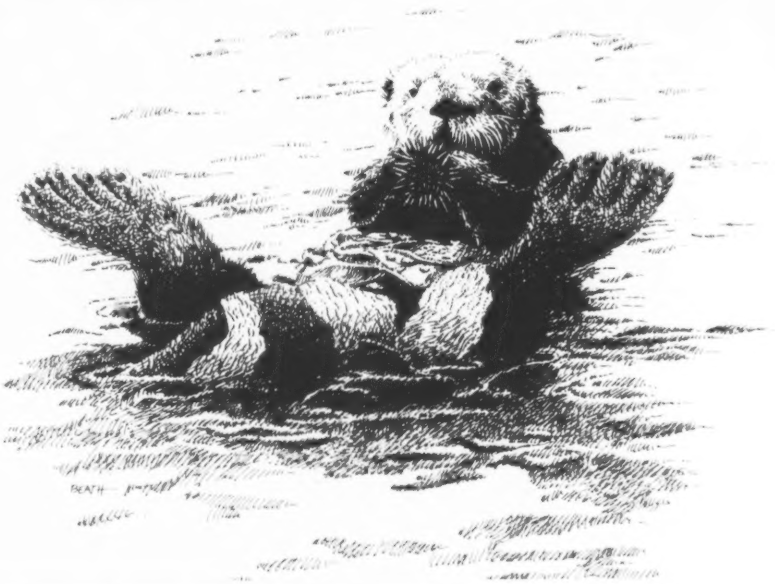
The three kelp zones are not independent of each other, and many animals are found in all three. The canopy habitat provides shelter and food sources to juvenile fishes. Among the most significant of these are kelp bass, topsmelt, kelp surfperch, blacksmith, and olive rockfish. Scientists have estimated that as many as 90,000 juvenile fishes may hide in a single acre of kelp. Many adult fish also find food and shelter in the kelp canopy.

Like the canopy, the mid-kelp habitat is used by many adult and juvenile fish. Most of the fishes found in this zone are also common in the canopy, but a few, such as the rubberlip and pile surfperches, are more likely to be seen below the canopy zone. In general, animal life in the mid-kelp region is not so varied or concentrated as in the canopy zone or in the bottom zone, the holdfast region.

The holdfast region with its tangled holdfasts, rocky nooks and crannies, and its many inhabitants, is the most complex of the kelp habitats. Many relatively short algae are found at the bottom of kelp beds where they form broad undulating understories and provide additional food and shelter for the bottom community. Thousands of species of animals are found at the bottom, some of the most characteristic being crabs, sea stars, rays, kelp bass, sheephead, and the nearly ubiquitous sea urchin.

In many places kelp beds are part of the otter-urchin-kelp ecological association in which the three species interact in a complex and interesting way. Kelp is the primary food of sea urchins, those often red or purple-

Figure 51: To keep from drifting with the tides and currents, sea otters sometimes wrap themselves in kelp fronds, thereby anchoring themselves to one spot.



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hued balls of spines related to sea stars. The urchins eat the lower parts of kelp plants, especially the holdfasts. Sometimes they eat enough of a plant to sever the stipes and cast the entire plant loose. If there are too many sea urchins, whole forests of kelp may be destroyed.

Sea otters prey upon sea urchins and find kelp beds to be almost perfect habitat. The kelp offers shelter from waves and provides plentiful food, including sea urchins. Where there are healthy populations of sea otters, sea urchin populations are kept in check and the kelp beds can flourish ***(Figures 51 and 52)***.

The otter-urchin-kelp association has effects far beyond its own little balanced system. Scientists studying Alaskan islands noticed that those islands with otters and kelp also have harbor seals and bald eagles. Islands without otters and kelp lack seals and eagles. After study, the scientists concluded that the kelp, maintained by the otters through their eating of the sea urchins, shelters large numbers of fish that harbor seals and bald eagles need for survival.

Figure 52: Fur hunters decimated the southern sea otter population off central and northern California by the turn of the century. The removal of this "keystone" species led to a dramatic increase in sea urchins grazing on kelp beds and to the consequent disappearance of many kelp beds.

Seabird and Pinniped Rookeries

The many places along the coasts and islands of America to which seabirds and seals return each year for breeding and rearing their young are called rookeries. These places are one of the keys to the survival of many species.

Seals, seal lions, fur seals, and walruses are called pinnipeds—meaning the feather-footed, a reference to the appearance of their flippers. There are about 33 species of pinnipeds, most of which can be found in rookeries at some time each year. Gulls, terns, pelicans, puffins, and other seabirds number in the dozens of species, many of which also return to rookeries annually.

At the rookeries, the animals are usually crowded in small areas to which each species returns year after year. Certain species of gulls, for example, make their shallow nests on level ground near the cliff tops of offshore islands. Their eggs and chicks are speckled brown to blend in with the colors of the dried grasses among which the nests are built. Puffins, on the other hand, prefer to nest on island cliff faces where they excavate burrows. Because puffins do not have to worry about predators, their eggs need no protective coloration and are whitish with various colored speckles. The choice of different nesting areas, the top of the cliffs for one species and the cliffs themselves for another, reduces the competition between species that breed at the same time ***(Figures 53 and 54)***.

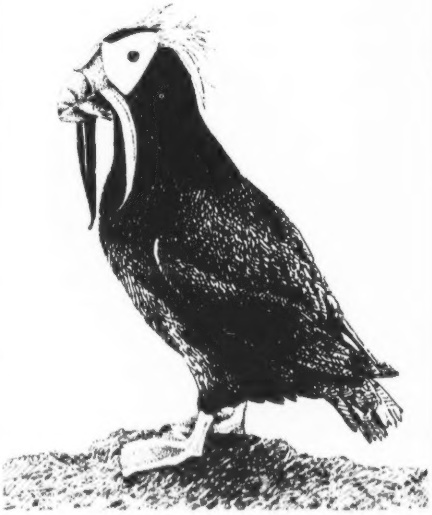

Figure 53: Tufted puffins use the Farallon Islands as a major rookery off the west coast of the United States.

Figure 54: Common puffins, like many other species of seabirds, use offshore islands as sites for their rookeries. The term rookery originally meant the noisy, dirty gathering places of large European crow-like birds called rooks.

Competition may be reduced in other ways as well. Species using the same sites can eliminate competition by using them at different times. California sea lions, for instance, gather for breeding in the early summer while elephant seals congregate in the early winter. Species using rookeries also crowd together in relatively small areas. Although crowding increases the competition within species for nesting or breeding territories, it reduces the competition between species for available space. Thus, each species is spared the necessity of competing with other species while ensuring that competition within the species keeps them strong.

The animals of the rookeries collect food from nearby waters. Seabirds forage as far as 20 to 100 miles from the rookeries, and pinnipeds, such as the northern fur seals of Alaska, search for food up to 150 miles from the rookeries. This foraging behavior collects and transports large amounts of nutrients over considerable distances to the rookeries.

A striking aspect of the ecology of pinniped and seabird rookeries is their seasonality. During the breeding season, large numbers of seals, sea lions and seabirds are tied by their young to a limited area. This large number of top-level predators has a tremendous effect on the populations of their prey. While this concentration of birds and pinnipeds is usually advantageous, climatic or other conditions can drastically reduce the populations of prey species, leading to decreased reproductive success of the top-level predators.

During the remainder of the year, the number of predators is greatly reduced and the pressure of the top-level predators is spread out over a large area as the birds and pinnipeds disperse to sites often far away. During this respite from intense predation, the prey populations may recover.

CASE STUDY

The Channel Islands

The Channel Islands, located just north and west of Los Angeles, support a larger and more diverse population of seals and sea lions than anywhere else in the world that is conveniently accessible to major centers of human population ***(Figure 45***, page 69). The Channel Islands are unusual in that they offer pinnipeds a place free of terrestrial predators, isolated from major human disturbances, and in the middle of cool, nutrient-rich waters. Harbor seals, elephant seals, northern fur seals, and California and Steller sea lions regularly breed at the Channel Islands, and a sixth species, the rare Guadalupe fur seal, is regularly seen there.

California sea lions are the most abundant pinnipeds of the Channel Islands, numbering about 70,000 or approximately half of the species' world population ***(Figure 55)***. Pupping and breeding activities occur on sandy beaches and rocky shores from late May through early September. Females breed within two weeks of giving birth and pups nurse for 5 to 18 months. Males aggressively defend territories in the rookeries against intruding males, but females are free to move from one territory to the next.

Steller sea lions are the largest of the eared seals of the northern hemisphere, with the males weighing up to a ton. The Channel Islands are at the extreme southern end of their breeding range. Their population at the islands is declining, a fact which some experts attribute to the recent recovery of the California sea lion population. It may be that after the population of the California sea lions was reduced by hunting, the Stellers were able to move in. Both species are highly territorial when on the rookeries: they pup and breed at the same time, and they may eat many of the same prey species.

Two species of fur seals are found at the Channel Islands, the northern fur seal and the Guadalupe fur seal. Like sea lions, they are members of the eared seal family but are distinguished from the sea lions by their thick dark coat and their longer hind flippers. Northern fur seals, once hunted to dangerously low levels by nineteenth century commercial sealers, recolonized the Channel Islands in 1968 where they established their only breeding colony in the eastern Pacific south of Alaska's Pribilof Islands. The Channel Islands' northern fur seal population numbers about 3,000 and uses remote areas of San Miguel Island for breeding. The population peaks in late August and by mid-December reaches its lowest level as most of the fur seals depart for pelagic overwintering. Like the sea lions, northern fur seals have a polygynous (poly=many, gyn=female) social structure, with territorial males violently protecting their home grounds and keeping their females together.

Guadalupe fur seals do not breed at the Channel Islands, but most observers believe that they will eventually. They appear once to have been the most numerous species of pinniped at the islands, although

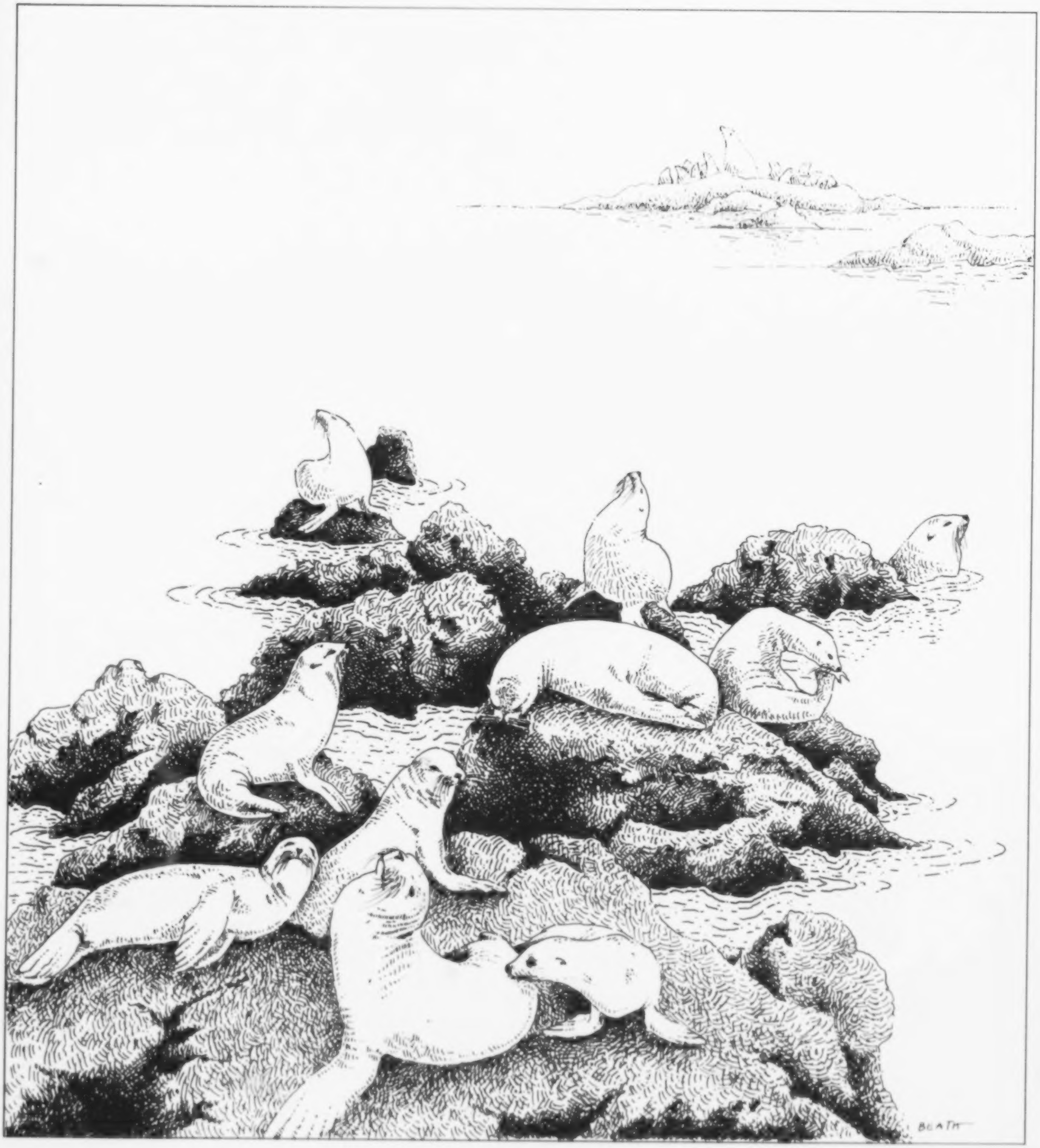
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Figure 55: California sea lions, like several other species of pinnipeds, use the Channel Islands for hauling out, breeding, and pupping.

today they are limited to a few individuals who haul out on the islands during breeding season. Twice the species was thought to have become extinct and was most recently rediscovered in the Channel Islands in 1949. Currently they breed only on Mexico's Guadalupe Island.

Elephant seals, members of the earless or true family of seals, are another species that was nearly driven to extinction by hunting, numbering less than 100 animals by 1879 ***(Figure 56)***. The species has made a remarkable comeback, now having a population of about 65,000, of which 25,000 live within the Channel Islands National Marine Sanctuary. Elephant seals are the largest pinniped of the northern hemisphere, with adult males weighing up to 6,000 pounds and adult females up to 2,000 pounds. They pup and breed from December to February using the sandy beaches of the islands.

The sixth species of pinniped at the Channel Islands is the harbor seal, another member of the earless family of pinnipeds. They breed from March to May and number some 4,000 individuals at the Channel Islands. They are not as gregarious as the islands' other species of pinnipeds and usually haul out on rocks individually or in small groups.

The pinnipeds of the Channel Islands are different in numbers and types from those found before the west coast was colonized and commercial hunting of the pinnipeds began. The populations continue to change. Species which do not compete for space can grow in numbers independently of each other. Species that do compete, such as California sea lions and Steller sea lions, may grow at the expense of each other. Should the Guadalupe fur seals reappear on the islands in any significant numbers, their effect on other species will be interesting to observe.

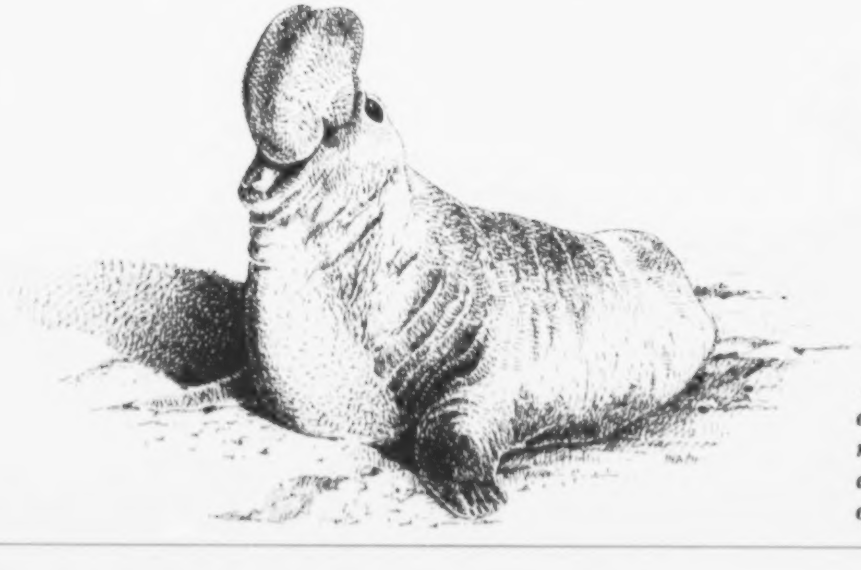


Figure 56: Male elephant seals are extremely territorial. Dominant males will confront any other male challenging his rule over a harem of female elephant seals.

MARINE ECOLOGY

Populations

Besides requiring energy, animals and plants require shelter, other nutrients, and reproductive mates. The manner in which these needs are met by various species of plants and animals in an ecosystem expresses some of the dynamics of that ecosystem.

Populations are the basic elements in any description of the biotic factors in an ecosystem. A population is a group of individuals of the same species that live in a given area. Thus, the humpback whales that feed in Alaskan waters can be considered a population of humpbacks. The humpbacks that feed at Stellwagen Banks off Massachusetts are from a different population.

The area where an organism lives is its habitat. A community is all of the populations living in a given physical habitat; the populations making up the community have a definite organization of feeding relationships and of transfer and use of energy.

Often communities are classified according to dominant species as in the kelp-urchin-otter community. Removal of the dominant species substantially changes the community. Communities may also be classified by the physical characteristics of the habitat, as, for example, the sandy beach community.

While populations of different species may occupy the same habitat, they have different ecological niches. An organism's niche includes not only where it lives within a habitat, but also what it does and how it is influenced by other species. In other words, an organism's niche is its role in the ecosystem. Two different species do not share the same ecological niche, although niches may overlap. Over time, species with similar niches specialize and differentiate their needs so that competition for food, shelter and space is reduced.

The size of a population within an ecosystem fluctuates depending upon a variety of factors. Extrinsic factors such as water temperature, predation by other species, and food supply are largely beyond the control of the population. The intrinsic factors of competition for food, stress caused by crowding, and the presence or absence of reproductive mates are produced with the population itself. Like other aspects of ecosystems, populations are always adjusting to internal and external changes ***(Figure 57)***. Successful self-maintenance and self-regulation leads to an equilibrium or homeostasis (homeo=same, stasis=posture) in which the flow of energy and nutrients into and out of the ecosystem is balanced.

The most familiar example of an extrinsic factor is the relationship between predator and prey. The predator population benefits itself by obtaining food from the prey population. The prey population may or may not be adversely affected by predation. In fact, predation may benefit a prey population by eliminating unfit individuals or by reducing competition for food.

In its simplest form, the predator-prey relationship is cyclic. As the predator population consumes a prey population, the predator population grows, leading to greater and greater predation on the prey population. As a result, the prey population declines and the predator population finds itself with less and less food. Due to the difficulty in finding food, the predator population declines, allowing the prey population to increase and beginning the cycle all over again. As noted previously, many predators do not feed on just one population but several. In such situations, a predator may consume one prey population, reducing its size, while other prey populations increase.

Competition among individuals of one species of plant or animal can have a greater effect on population size than external constraints do. In one example of this competition, an individual member of a population defends a particular territory against intruders of the same species. Individual organisms may do this to insure access to specific habitats, to food, or to sexual partners.

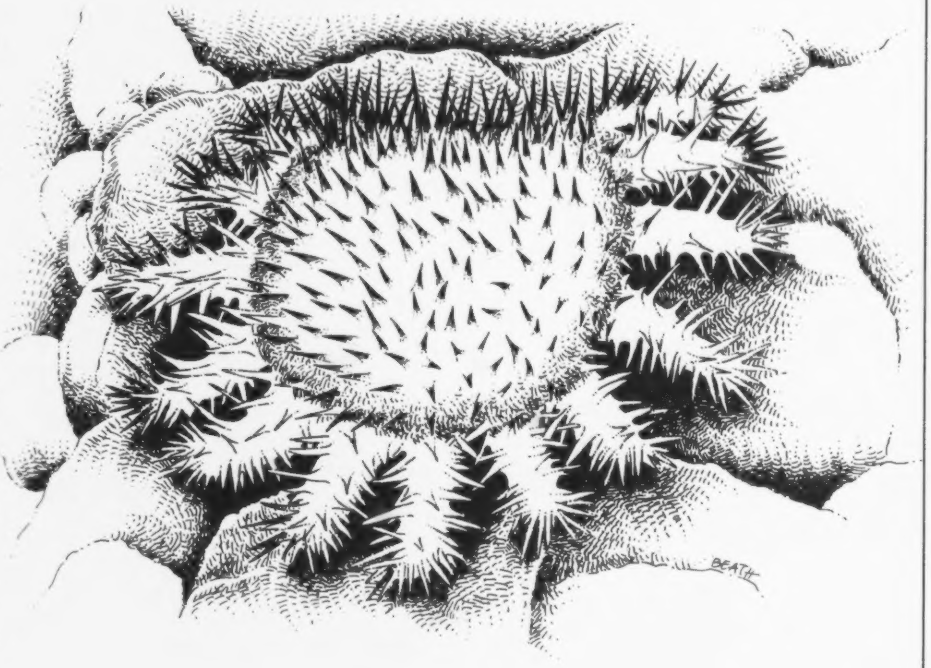


Figure 57: In response to unknown environmental factors, populations of the crown-of-thorns starfish periodically explode, wreaking havoc on coral reefs in the Indo-Pacific. A recent incursion of these animals is being studied at the most recently designated national marine sanctuary at Fagatele Bay in American Samoa.

NEARSHORE ARCTIC ECOSYSTEMS

North of Alaska are parts of the Arctic Ocean known as the Beaufort and Chukchi Seas ***(Figure 58)***. These cold, shallow waters are the locations of some unusual ecosystems in which one physical factor—ice—is often the overriding determinant of species distribution and seasonality. Although sea water has a freezing temperature much lower than that of fresh water, beginning in October the waters of the Beaufort and Chukchi Seas annually freeze solid to a depth of at least six feet, and they do not become clear again until the following June.

The combination of the thick ice with the far northern location, where the sun shines for only part of the year, means that most of the time the waters of the seas are pitch black. Plants and animals have made unusual adjustments to this fact of arctic life.

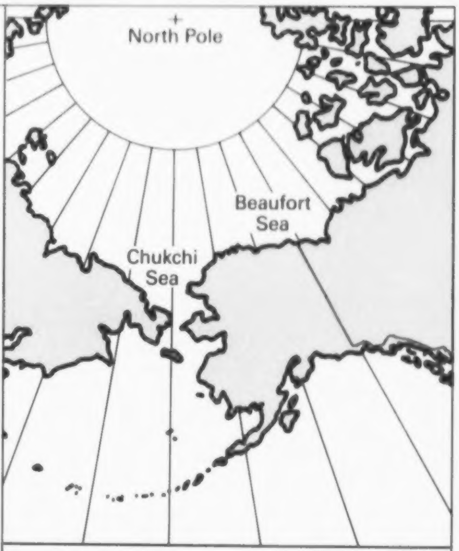


Figure 58: Much of the Beaufort and Chukchi Seas remain little explored wildernesses, concealed as they are for much of the year by pack ice.

Arctic Seafloor

The rivers that empty into arctic seas have laid down vast deposits of mud as they have flowed down from the Brooks Range for thousands of years. In most respects arctic muddy bottoms are no different from other soft bottom marine ecosystems except for one factor: the annual ice scouring they receive. Newly formed ice near the shore can be broken up by winds and waves. Ice floes, large blocks of thick floating ice that are driven about the Arctic Ocean by currents, displace and deform the ice, sometimes moving it distances of several miles or piling it up into ridges many feet thick. As the ice moves in response to winds and currents, the ridges move too. Often they scrape along the bottom of the shallow sea floor creating gouges hundreds of yards long, up to fifty yards wide, and as deep as 15 feet. In some places dozens of these gouges can be found offshore for each mile of coastline.

When the ice ridges gouge the bottom they destroy part of the sea bottom habitat by plowing it up and killing, exposing, or burying the inhabitants of the mud. But they also create new habitat as formerly buried bottoms are exposed to colonization and the gouged-up sediments are reworked and distributed by the water currents. The same thing that happens to the silt of the sea floor also happens to the bottom of the ice, which usually features a growth of algae. When the ice scrapes the sea bottom, the algae on the ice are killed, scraped off, or buried in the ooze. This creates new areas for algae to grow on the bottom of the ice.

The first few divers who ventured into the cold and dark waters of the arctic described the seafloor as flat, featureless, and lifeless. Closer looks, however, have shown that the seafloor, while perhaps flat, is not featureless, and is far from lifeless. Within the mud, numerous forms of filter-feeding worms and clams are found. These animals feed on detritus, plankton, and algae, and are in turn the main source of food for cod, char, whitefish, capelin, and smelt.

The ice-gouged sea bottom of the arctic is an outstanding example of how the physical characteristics of an area shape an ecosystem. Life in the frigid waters of the arctic is adapted to the conditions of a silty bottom, freezing water, and constant reworking of the sediment by ice.

Boulder Patches

Here and there in the vast muddy ooze of the arctic marine world are extensive clusters of boulders and cobbles, covered with anemones, sponges, and soft corals ***(Figure 59)***. Deposited thousands of years ago by glacial icebergs that originated far to the east, the boulder patches are oases of hard-bottom life in a soft-bottom sea, featuring kelp beds and other algae. The kelp of this arctic world grows in the darkness of late winter and early spring and uses the sunny summer days to manufacture and store carbohydrates to fuel its growth.

Arctic boulder patches are examples of how nature takes advantage of an accident. The rocks that make up the boulder patches came from far away. There are no other hard bottom communities in the immediate area from which creatures might quickly move to take over the rocks. Instead, the colonization of the boulder patches appears to have been a matter of luck in which many, many individual creatures were swept far from their normal environment and a few found the boulders. They lived and even thrived. Others found nothing suitable on which to attach themselves, and they died. The few survivors eventually covered the rocks and established new arctic ecosystems. The result is that today the boulder patches are integral parts of the life in far northern waters.

Life in the boulder patches is diverse and dense. Scientists have identified over 300 species at a single boulder patch, including a few species which were previously unknown to science. Given the harshness of the arctic environment, the number and kinds of species that are found in the boulder patches are exceptional. The rocks themselves are seldom visible, being covered by thick encrustations of pink algae, soft corals, anemones, hydroids, and sponges. The plants and animals are a mixture of Atlantic and Pacific types, plus a few uniquely Arctic types, making the boulder patches melting pots of North Atlantic and Pacific species.

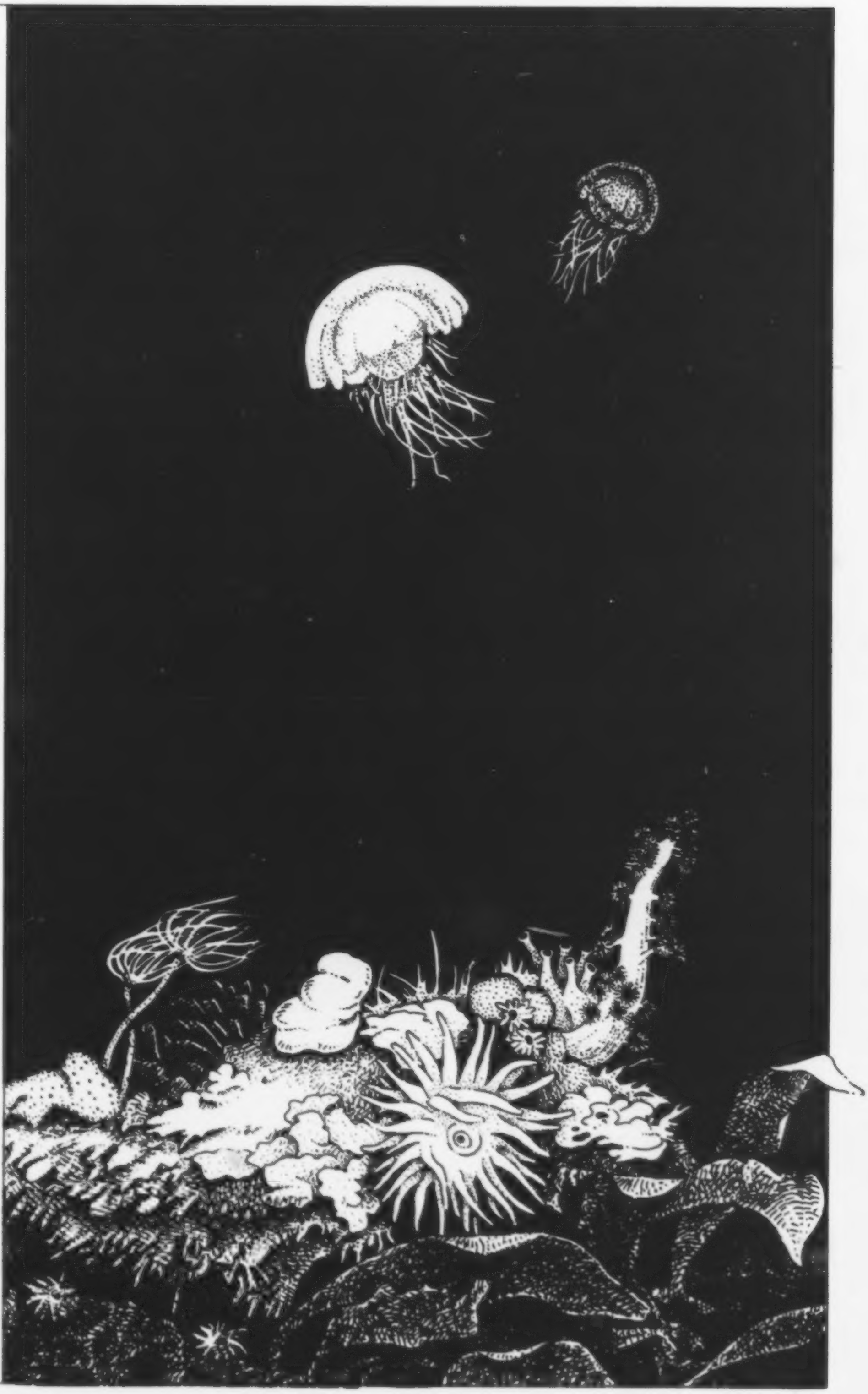


Figure 59: Boulder patch communities are shrouded in darkness for much of the year. The richness of life in these habitats has surprised scientists.

MARINE ECOLOGY

Distribution of Invertebrates

Crabs, barnacles, sea urchins, sponges, and other marine invertebrates are found throughout the oceans. Attached invertebrates such as barnacles and anemones are able to colonize distant new habitats such as Arctic boulder patches or coral reefs despite the fact that unlike many larger, more mobile marine animals, adult benthic marine invertebrates generally cannot move very far. Rather, the colonization of new habitats and the recolonization of old habitats depends upon the reproductive techniques these animals have developed.

Few marine invertebrates give birth to live young. Most begin life as eggs floating free as part of the zooplankton. Quite often the eggs of attached marine invertebrates are not fertilized when released. Fertilization occurs in the open water. In order to overcome slim odds of a sperm fertilizing an egg in open water, individuals of many of these species release thousands, even millions, of eggs in a single season. Even then, a fertilized egg, carried about by ocean currents and exposed to predators, does not stand a good chance of becoming an adult.

When the egg of a marine invertebrate, such as a barnacle, a shrimp, or coral, has hatched, it does not immediately assume an adult form ***(Figure 60)***. As a larva, it will undergo a number of transformations before achieving even

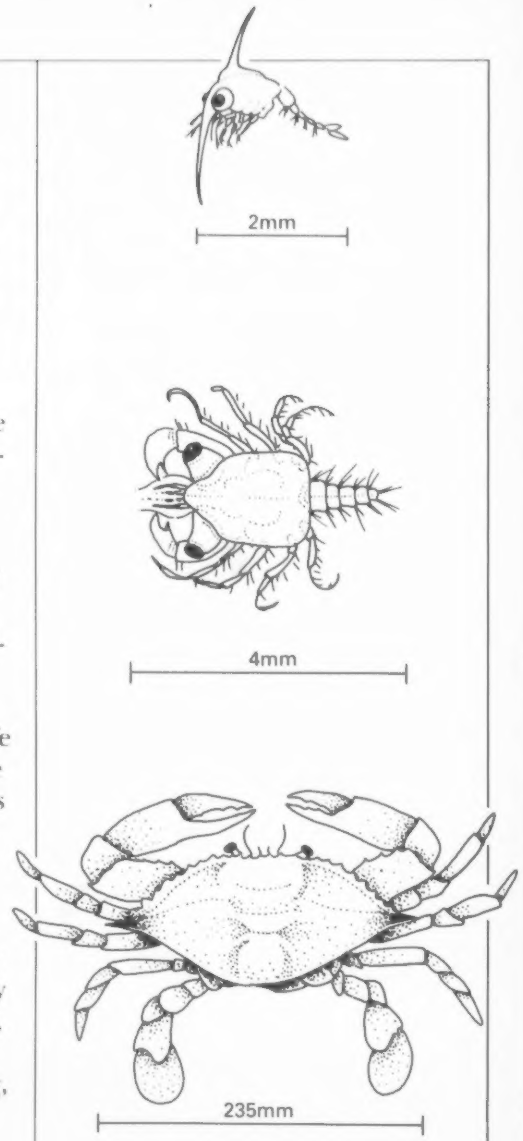


Figure 60: Three stages in the development of a blue crab. In the first two (larval stages) a blue crab is largely planktonic. Only when it reaches its juvenile form (bottom) does a blue crab enjoy any independence of movement.

its juvenile form. In many cases the larva initially looks like a small, translucent top, spun about by bands of waving cilia (=small hairs). The light weight of the larva keeps it suspended in the water, and its translucency provides some protection against predators. The power of a larva to move about, however, is extremely limited. As a result, the larvae of marine invertebrates become part of the drifting zooplankton feeding on other zooplankton or phytoplankton.

The release of fertilized or unfertilized eggs by many marine invertebrates appears to be timed to coincide with periods when there is abundant phytoplankton. As a result, blooms of phytoplankton often precede blooms of larval zooplankton. This, in turn, depletes the phytoplankton while making food available to organisms, such as herring, that feed on zooplankton. These consumers themselves become food for larger consumers such as other fishes, whales, and seabirds.

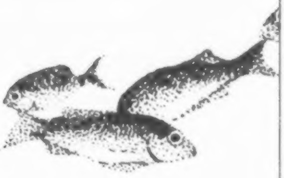
Over succeeding hours, days, weeks, or even months, a larva will change its form. For example, as the larva of nemertine worms develop, the organs of the worm-to-be are gradually enclosed in separate pockets formed from the outer walls of the larva. The little worm then separates itself from the remainder of the larva, which has served as a floating receptacle, and drops to the seafloor where it begins life as a fully formed juvenile worm. The rest of the larva continues swimming about until it dies for lack of nourishment.

The larvae of attached marine invertebrates must not only brave predators, but they must also find a suitable substrate for attachment. Carried about by waves, currents, and tides, the larvae of barnacles, for instance, are unlikely to find a clean substrate with the proper water temperature and light. Thus, most die. Nonetheless, the larvae of some marine invertebrates are able to discriminate between suitable and unsuitable sections of a substrate and to move about until they find a suitable section.

Although such a reproductive strategy may not be beneficial for the individual egg, it is beneficial for the species, particularly those which spend their adult lives attached to the ocean bottom. By having its larvae float freely, the species is able to disperse itself over a wide area and colonize suitable habitats. If a local population of coral has been destroyed, for instance, the population may be reestablished by means of the arrival of larvae from other coral reefs.

The larvae of many marine species play an important role in the distribution of species in the oceans. What is more, as important components of the zooplankton, larvae are an important link in the food web which supports much of the life of the oceans.

CONCLUSION



As our understanding has grown of the relationships among marine animal and plant life and the physical environment of the oceans, so has our recognition that we humans do not stand apart from the life of the oceans. Whether we harvest renewable resources or dump our wastes into the oceans, we affect the way in which marine ecosystems work. In some cases, we know that our activities jeopardize the health and productivity of marine areas. In many more cases, however, we do not know the effect of our activities upon the long-term productivity of the oceans. Because ocean waters can transport whatever is put into them over thousands of miles, the origin of pollution found in a particular area is often very difficult to trace. Likewise, the effects of the harvest of one species upon other species in an ecosystem are often unknown.

In the future, our need for an understanding of the effects of human activities will increase. At the same time, prudence dictates that, as with our terrestrial heritage, we seek to conserve outstanding examples of our marine heritage for the enjoyment of future generations and for study of the interrelationships among the oceans' living and non-living resources.

In 1972, the U.S. Congress established the National Marine Sanctuary Program through Title III of the Marine Protection, Research and Sanctuaries Act (P.L. 92-532). In 1984, Congress defined the purposes of the program in P.L. 98-498. These purposes are:

1) to identify areas of the marine environment of special national significance due to their resource or human use values;
2) to provide authority for comprehensive and coordinated conservation and management of these marine areas which will complement existing regulatory authorities;
3) to support, promote, and coordinate scientific research on, and monitoring of, the resources of these marine areas;
4) to enhance public awareness, understanding, appreciation and wise use of the marine environment.

The National Marine Sanctuary Program is administered by the Sanctuary Programs Division in the Department of Commerce's Office of Ocean and Coastal Resource Management. Since 1972, seven sanctuaries have been designated *(see map on end papers)*:

U.S.S. Monitor National Marine Sanctuary: This sanctuary was designated in January, 1975, and is an area one mile in diameter southeast of Cape Hatteras, North Carolina. It protects the wreck of the Civil War ironclad, the *U.S.S. Monitor.* The sanctuary provides an excellent opportunity to increase public awareness of an important American historical and cultural resource.

Key Largo National Marine Sanctuary: This sanctuary, designated in December, 1975, provides protective management of a 100 square-mile coral reef area south of Miami. The sanctuary contains four distinct biological zones: 1) coral reef areas consisting of reef banks at the seaward edge of the shelf margin and numerous patch reefs on the landward side; 2) hardground areas veneered with hard and soft corals; 3) seagrass areas, which serve as nurseries for many organisms; and 4) sand areas interspersed with patches of grass. Populations of commercially important stone crabs and spiny lobster and recreational species such as grouper, snapper, and pompano also are found in the sanctuary area. The area contains many structures and objects such as a lighthouse and sunken ships with associated artifacts.

Channel Islands National Marine Sanctuary: Designated in September, 1980, this sanctuary covers an area of 1,252 square nautical miles surrounding the northern Channel Islands and Santa Barbara Island off the coast of California. The area supports one of the largest and most varied assemblages of marine mammals in the world. The sanctuary is also a focal point for one of the richest resource areas for seabirds in the United States, based on both the numbers of individuals and the diversity of species. Seabird concentrations occur not only on the islands and offshore rocks, but also on the productive waters around the islands where many species forage. The endangered brown pelican breeds on Anacapa Island and forages in sanctuary waters. The nearshore island waters in the sanctuary are major southern California producers of such species as abalone, sea urchins, and rockfish.

Looe Key National Marine Sanctuary: This sanctuary, designated in January, 1981, consists of a five square nautical mile section of the Florida reef tract southwest of Big Pine Key. The site includes a beautiful "spur and groove" coral formation and supports a diverse marine community and a wide variety of human uses. A diverse array of invertebrates and fishes inhabit the overhangs, crevices, sand flats, and other microhabitats created by the coral and adjacent areas.

Gray's Reef National Marine Sanctuary: This site, designated in January, 1981, is a submerged hard bottom area of 17 square nautical miles located on the south Atlantic continental shelf due east of Sapelo Island, Georgia. It is one of the largest nearshore hard bottom reefs in the south Atlantic and supports a diverse array of temperate and tropical species, including seaweeds, corals, sponges, shellfish, tropical ornamental reef fishes, and a variety of gamefishes. Sea turtles and marine mammals, primarily dolphins, are frequently seen in the area.

Point Reyes-Farallon Islands National Marine Sanctuary: This sanctuary was also designated in January, 1981, and encompasses a 948 square nautical mile area off the California coast north of San Francisco. In the waters off Point Reyes and around the Farallon Islands significant seabird and marine populations thrive. In fact the Farallon Islands support the largest seabird rookeries in the contiguous United States. Whales, including several endangered species, and porpoises pass through the sanctuary on their annual migrations. California sea lions, harbor seals, and elephant seals use the extensive feeding grounds and the shores of the Farallon Islands for hauling out and pupping. Finally, the waters provide substantial recreational and commercial fishing opportunities.

Fagatele Bay National Marine Sanctuary: On April 29, 1985, Fagatele Bay in American Samoa was designated as the seventh national marine sanctuary. Located 2,300 miles southwest of Hawaii, this sanctuary contains a coral terrace system that provides a diversity of habitats for marine fishes and turtles, for instance. Fagatele Bay was formed in recent geologic times when the seaward wall of a volcanic crater collapsed.

During 1981 and 1982 the Sanctuary Programs Division developed a Program Development Plan that sets forth the goals and purposes of the program, various policy aspects of sanctuary designation, and considerations in the development of management plans for sanctuaries. In implementing this plan, the Sanctuary Programs Division initiated a new process for reviewing sites nominated for sanctuary designation. Under the Site Selection Process, a team of scientists for each of eight biogeographical regions reviewed available information on possible sites against criteria set out in the Program Development Plan. Based on this review, and a review by the public, the Sanctuary Programs Division selected 29 sites that will receive further consideration for sanctuary designation.

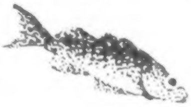
Although additional sites may be added to the list later if they are of national significance, this Site Evaluation List will provide a guide for development of the National Marine Sanctuary Program in the future. In moving to designate any site, the Sanctuary Programs Division will prepare and issue a variety of documents, including environmental impact statements, to be reviewed by other federal agencies, state governments, industry and conservation groups, and individuals.

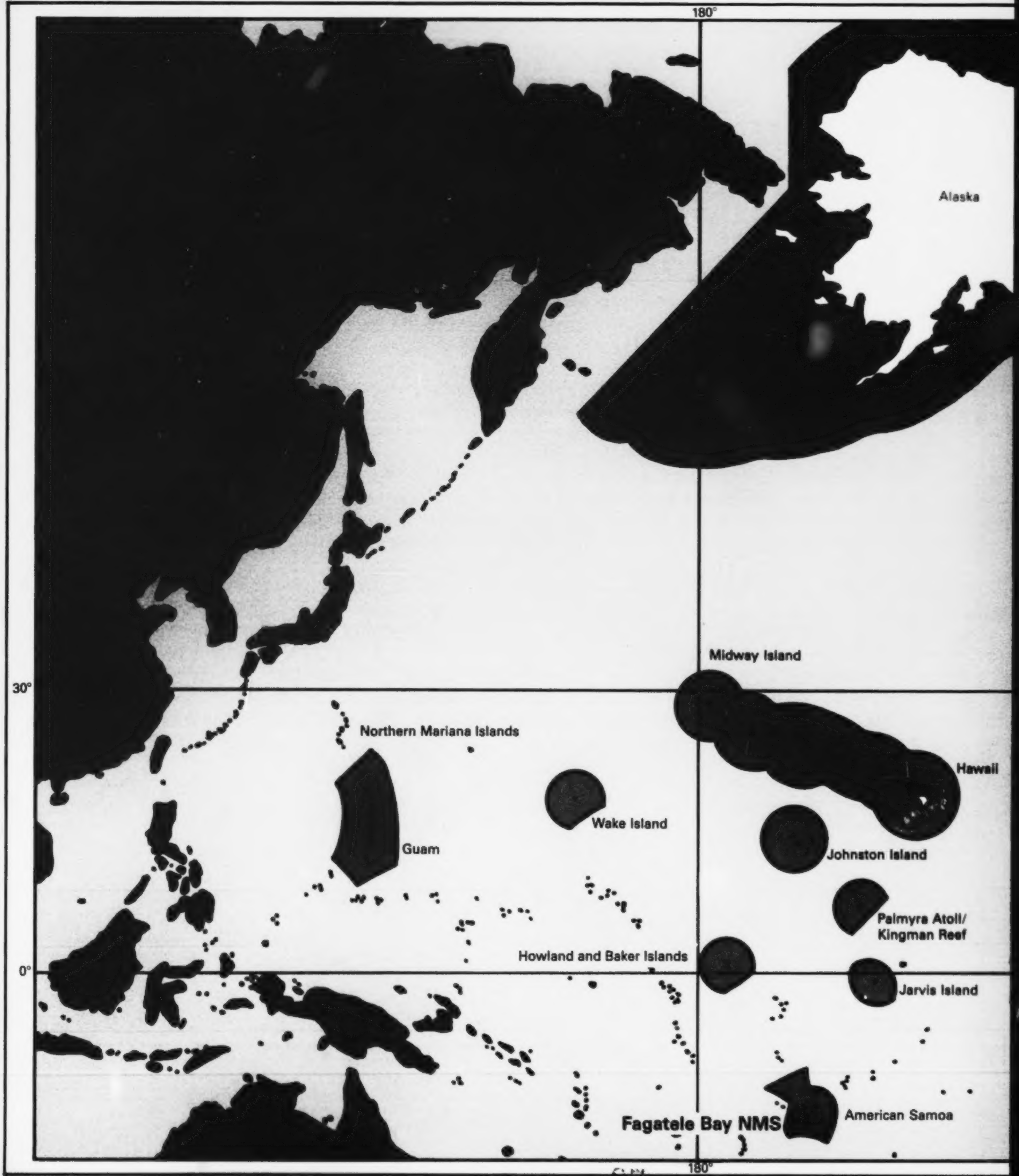
Each designated sanctuary will have a management plan that will set out programs for meeting the conservation, research, and educational objectives of the designation. These plans will differ with each sanctuary, although they will all contribute to the program's national goals.

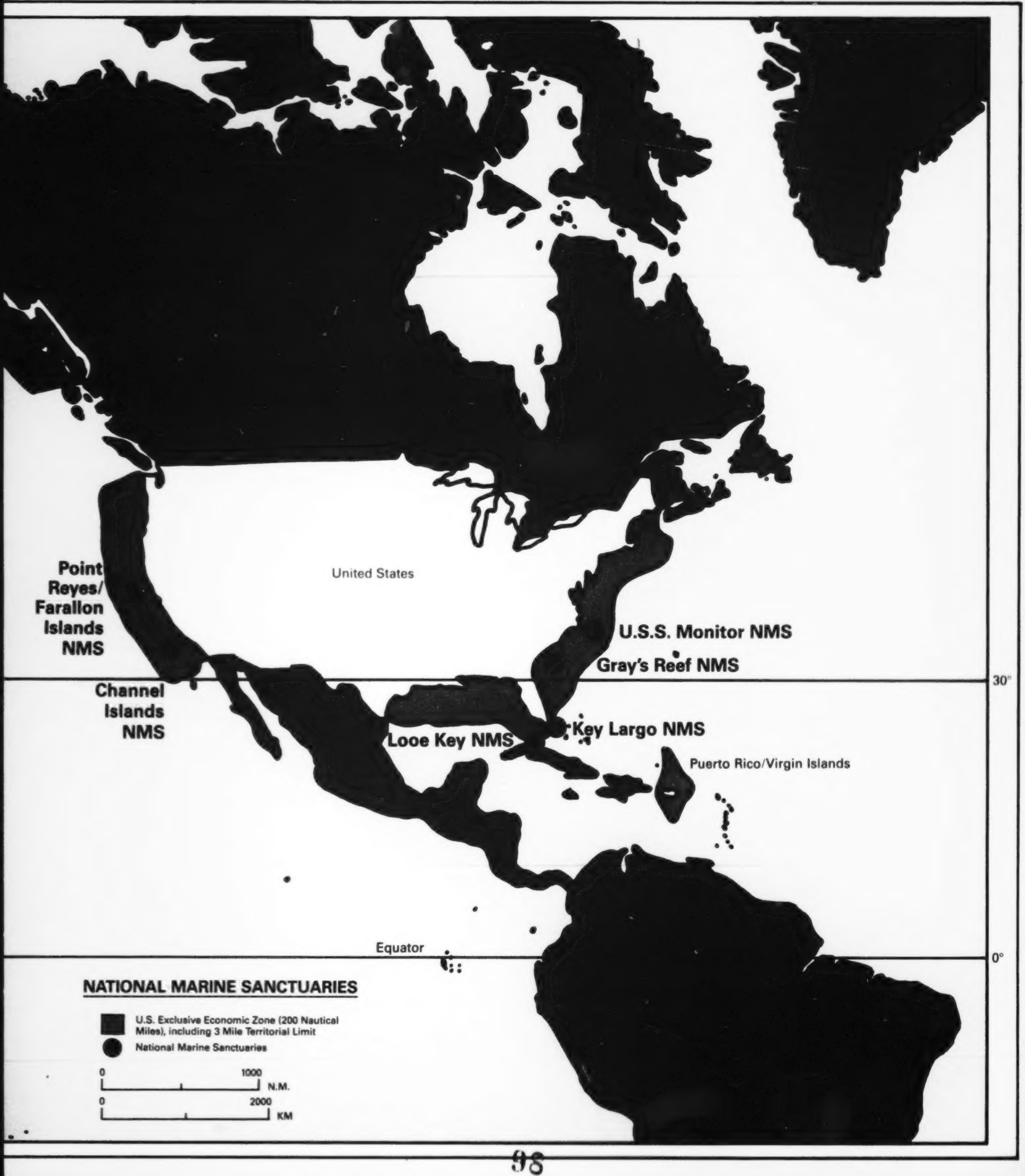
In the coming years the National Marine Sanctuary Program will continue to meet the challenge that Congress has set before it. With its mandate to comprehensively manage distinct marine areas the program will conserve not just one part of what makes an area special, such as whales or coral, but the integrity of a marine ecosystem. With its continuing programs of research and education the program will increase our appreciation for the critical role that oceans play in the life of our nation. And most importantly the program will provide citizens and decisionmakers with the information needed for making the intelligent choices that the future will require of us.

For more information about the National Marine Sanctuary Program, please write:

Sanctuary Programs Division
Office of Ocean and
Coastal Resource Management
1825 Connecticut Avenue, NW
Washington, D.C. 20235




180°
Alaska
Midway Island
30°
Northern Mariana Islands
Hawaii
Wake Island
Guam
Johnston Island
Palmyra Atoll/
Kingman Reef
Howland and Baker Islands
0°
Jarvis Island
Fagatele Bay NMS
American Samoa
180°



NATIONAL MARINE SANCTUARIES

Point Reyes/ Farallon Islands NMS
Channel Islands NMS
United States
U.S.S. Monitor NMS
Gray's Reef NMS
Key Largo NMS
Looe Key NMS
Puerto Rico/Virgin Islands
30°
Equator
0°
U.S. Exclusive Economic Zone (200 Nautical Miles), including 3 Mile Territorial Limit
National Marine Sanctuaries
0
1000
N.M.
0
2000
KM

The oceans include a startling array of ecosystems. Scientists believe that off the coasts of the United States, from the frigid ice-scoured waters of the Arctic Ocean to the tropical reefs of the Florida Keys, the West Indies, and the Pacific islands, there are more kinds of marine plants and animals in more kinds of marine habitats than are found off any other country in the world.

A Nation of Oceans will take you on a journey that will help you understand differences and similarities between the life of the oceans and our own. Perhaps, when you next gaze beyond the water's edge, the oceans will reveal a new meaning to you because you have come with a new understanding.

The **National Marine Sanctuary Program** seeks to conserve outstanding marine areas for future generations by managing human activities that may damage their integrity. Through research and educational activities the program also seeks to increase scientific understanding of marine ecosystems and to inform the public about the wise use of marine resources. In the future, the pressures on our marine resources will mount and the need for an informed citizenry will become even more pronounced. The National Marine Sanctuary Program is making its own unique contribution to insure that this need is met.

The **Center for Environmental Education,** established in 1972, is a conservation organization dedicated to protecting marine wildlife and their habitats, and to conserving coastal and ocean resources.

For further information about the programs of the Center for Environmental Education write:

Information
Center for Environmental Education
624 9th Street NW
Washington D.C. 20001